THE RINCÓN ASTROLABE SHIPWRECK

A Thesis

by

GUSTAVO ADOLFO GARCIA ORTIZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

December 2005

Major Subject: Anthropology

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Approved by:

Chair of Committee,	Luis F. Vieira de Castro
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ABSTRACT

The Rincón Astrolabe Shipwreck. (December 2005)

Gustavo Adolfo Garcia Ortiz, B.S.C.E., Polytechnic University of Puerto Rico

Chair of Advisory Committee: Dr. Luis F. Vieira de Castro

On 30 December 1986, a local fisherman incidentally discovered the remains of a seventeenth-century merchantman off the coast of Rincón, a small municipality on Puerto Rico's west coast. Some days later, he and some acquaintances extracted objects from the site and stored them in a nearby restaurant. The assemblage of artifacts recovered included, among other items, pins, scissors, ordnance, pewter ware, woodworking tools, a myriad of concretions and a nautical astrolabe. It is from the last that the wreck site took its name. The operation continued for months until local authorities, alerted by a member of the salvage group, issued a cease and desist order. At that point, the whole affair entered a legal process that on the summer of 2005 had not reached its conclusion.

The purpose of this thesis is twofold. First, the author presents the story of the shipwreck from the moment it was found until the court ruled regarding ownership of the artifacts. Since this was the first time ownership of a shipwreck was debated in Puerto Rican courts in recent history, this gives the reader an idea of how legal precedence was established concerning the island's submerged cultural resources. Second, based on what was popularly perceived to be the site's most remarkable find, a study was developed on the sea or mariner's astrolabe, a navigation instrument that

played a fundamental role in the process of European maritime expansion during the late fifteenth, sixteenth and seventeenth centuries.

The reader of this text will learn that, during the fifteenth century, Portuguese navigators saw the need to gradually depart from the traditional Mediterranean navigation technique known as 'dead reckoning.' As their explorations along the West African coast forced them to sail far into the Atlantic Ocean for prolonged periods, a new method was developed that consisted of measuring the angle of certain heavenly bodies above the horizon in order to determine the latitude of the observer with reasonable precision. For this purpose, instruments that traditionally belonged to the field of astronomy were adapted to be used by seamen. Among them was the astrolabe, which became the most popular by the turn of the sixteenth century. After discussing the instrument's origin and development, the author analyzes how a renewed interest on the nautical astrolabe, which emerged in Portugal in the early twentieth century, introduced the instrument to the field of modern scholarly research. This work also presents a catalogue of sixteen sea astrolabes, some of which have never been published. The catalogue shows statistics and other relevant information, while placing the artifacts in the context of the previously existing data.

DEDICATION

A mis padres, mis mecenas

ACKNOWLEDGEMENTS

It has been six years since that January evening when I arrived in Texas with the "crazy" idea of becoming a nautical archaeologist. Many things have happened in my life since then, some of which conclude with the completion of this work. To many persons I am indebted for their contribution, in one way or another, to the fulfillment of this dream: Dr. Filipe Castro, chair of my committee, professor and friend, through you I discovered a wonderful place called Portugal. It lives in my heart. *Muito obrigado maestro*. Dr. Jerome Lynn Hall, who shares with me great love for my homeland Puerto Rico - you had faith in me. Hopefully, I will run into you again some day in the streets of Amsterdam. *Luctor et Emergo*. Dr. Kevin Crisman, who allowed me to be part of the 2001 Portugal and Azores expedition, which has been one of the most influential experiences of my life - for that I am grateful. Barbara Aufranc, my Guatemalan friend in Texas, it was really a pleasure.

Out of Texas, I would like to thank Carmen López Calderón of the *Museo Naval* in Madrid for the information provided on the two astrolabes held by that institution; Greg Stemm and John Opperman of Odyssey Marine Exploration, for allowing me to analyze the instruments owned by that organization and coordinating my visit to Numismatic Conservation Services in Sarasota, Florida; Wyatt Yeager, of Numismatic Conservation Services, for his assistance and kindness while I visited their facilities.

Back home, I would like to especially thank my sister Jomara, who patiently held with me endless telephone conversations when the tedium of College Station seemed to

be unbearable on many Sunday afternoons; my nephews Miguel and Gerry, and my niece Charleen, for their image that was always in my mind and their love in my heart. To be closer to you I returned home. Life will find its way. Last but not least, I am indebted to my girlfriend Vanessa Amado, wonderful companion, source of sanity and software guru. Many times she had to hear the expression “I ought to get done writing that thesis!” Well dear, here it is.

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INTRODUCTION

Humankind has been using the sea as a means for transportation since time immemorial. The development of technologies that would guarantee a successful interaction with this inhospitable environment can be traced to the earliest civilizations. One of the permanent problems seamen confronted as they took to the oceans was the creation of methods that would allow them to determine their position and the direction in which they traveled as they struggled to take their ships safely and efficiently between ports. For millennia, when sailors wanted to have an idea of their approximate location, they had to rely on rudimentary techniques and the experience they had gained during their life at sea. This began to change in the fifteenth century, when the Portuguese fused astronomy with seafaring in an attempt to develop procedures that would allow navigators to have a relatively precise idea of the position of their vessels as they traveled along the West African coast.

Landmarks were among the earliest navigation aids mariners used.[1] Although the idea that early seamen always navigated close to shore is a misconception, it is likely that they avoided being out of sight of land for prolonged periods. To assist him in his daily doings, an experienced pilot would memorize characteristic coastal features and use them for orientation purposes. Those who ventured far from shore were guided by the sun and a rough knowledge of the position of certain stars.[2] The use of celestial bodies as an aid to navigation appears in the historical record since Pre-Classical times.

This thesis follows the style and format of *The Mariner's Mirror*.

Proof of this can be found in the *Odyssey*, where the Greek poet Homer describes how Odysseus was instructed by the goddess Calypso to keep the Ursa Major to port as he left the island of Gozo.[3] A later allusion to celestial navigation appears in the New Testament book *Acts of the Apostles*. The episode narrates how the crew of St. Paul's ship felt hopeless when, during a dreadful storm, some days passed without the men being able to see neither the sun nor the stars.[4] Nevertheless, it is almost certain that the observations made in these situations did not involve taking any measurements. Instead, sailors determined east-to-west direction by sunrise and sunset, and at night they noticed the position of the North Star.[5] Arguably, the earliest known evidence for the elevation of a celestial body being analyzed for orientation purposes at sea comes from the writings of the Roman poet Lucan (*c.* A.D. 65).[6] The passage describes how the captain of a ship in the Mediterranean relates the position of certain stars to the masts and spars of his vessel and associates it to different ports.[7]

Another source of guidance used by ancient sailors in the Mediterranean was the wind. Seamen noticed that certain airstreams always blew from particular directions and they named them after the regions in which they perceived the winds originated.[8] The composition of the ocean floor was also a significant aid to mariners, both in the Mediterranean and in northern Europe.[9] In order to obtain a sample of the seabed, seamen used a lead weight tied to a line. The weight was hollow at its bottom, so that it could hold a lump of tallow. When it was thrown overboard, mariners were able to determine water depth according to the amount of line released. The material from which the seafloor was composed adhered to the tallow, providing the navigator with valuable information. A rapidly decreasing depth suggested the proximity of the shore or a shoal. Additionally, an experienced sailor would be familiar with the composition of the sea bottom in the regions he frequented. Seamen used these and other simple navigation techniques throughout antiquity, without any significant changes taking place until the Late Middle Ages.[10] As the Dark Ages evolved in Europe, to the east, the Greeks and the Arabs were making great progress in most scientific fields, including astronomy.[11] The knowledge they accumulated entered Europe through the Iberian Peninsula during the Muslim occupation, which began in A.D. 711.

A turning point in the history of European navigation took place in the eleventh century, with the introduction of the magnetic compass.[12] The origin of this instrument is obscure, and modern historians argue about an Asian or Scandinavian birthplace. In any case, its use was widespread among the Catalonians, Genoese and Venetians during the thirteenth century. Using the compass and the Portolan chart, mariners were able to determine -albeit roughly- their position by a practice known as 'dead reckoning.'[13] Using this method, a pilot was able to estimate the location of his vessel based on the direction in which it traveled, the speed and the time elapsed. However, the great revolution in European navigation began in the fifteenth century in Portugal.

The event accepted by most scholars as the starting point of the great advances in navigation technology made during the fifteenth century is the capture of Muslim Ceuta by the Portuguese in 1415. João I was king of Portugal at the time and his son Henry (1394-1460) participated in the operation. Throughout his life Prince Henry was a fervent Catholic who thought of himself as a Christian crusader destined to bring the war against African Muslims to their home continent. Especially fascinating to Henry was the idea of finding the realms of Prester John, a legendary Christian king whose dominions were supposedly located somewhere near modern Ethiopia. Henry believed that he had the moral obligation to make contact with Prester John, in order to establish an alliance between the European and African Christian kingdoms, so that they could wage war against the 'heathens' from two fronts. A worldlier objective that the Prince is also likely to have pondered was the possibility of finding the seemingly inexhaustible sources of African gold that had for centuries supplied a substantial amount of the precious metal to Europe.[14] With these reasons in mind, Henry undertook the exploration of the West African coast, an endeavor for which he would eventually become a prominent historical figure.

Although the existence of a navigation school founded by Prince Henry at Sagres has for years been a topic of debate among historians,[15] it is a fact that great advances were made in Portugal in all branches of nautical knowledge during Henry's lifetime, mostly under his patronage. To assist him, Henry surrounded himself with people learned in astronomy, a science that was for centuries inextricably linked to astrology and cartography. It was during this period that for the first time astronomers and scientists worked hand-in-hand with seamen to develop a new method of navigation, based mainly on measuring the altitude of a celestial body in order to determine the latitude of the observer. As scientists and navigators collaborated, the Portuguese began to push south along the west coast of Africa.

One of the major problems Portuguese sailors confronted after they rounded Cape Bojador in 1434 was that, on the returning portion of the trip, the winds blowing from the northeast drove them away from their homeport. As wind patterns were studied, they discovered that to the northwest, by the Azorean Archipelago, the winter winds made returning to Portugal easier while sailing eastwards. The problem was that, to reach this location, mariners had to sail hundreds of miles out of sight of land. So far from their objective, and traveling through the open sea, they became disoriented. It was hard for them, after deviating far out into the ocean, to end their trip anywhere close to their destination.[16] At that point, astronomers developed the technique of sailing by *altura,*[17] which consisted of measuring the altitude of the North Star and associating it to latitude. Mariners returning to Europe could sail northwest from Africa to find the suitable winds, and then steer their vessels eastward. Knowing the *altura* of their homeport, they only had to turn slightly north or south, until they reached the appropriate latitude.

Because the North Star does not precisely coincide with the celestial pole, its altitude does not represent the exact latitude of the observer. To solve this situation, a set of rules was created that allowed mariners to convert elevation to latitude, by relating the position of the polestar to that of *Kochab*, another star in the constellation Ursa Minor.[18] The manual containing these rules was known as the "Regiment of the North Star." Although a simple concept, it allowed sailors for the first time to have a reasonably precise idea of their position in terms of distance from the equator.[19] In 1454, while on an expedition under the auspice of Prince Henry, the Venetian pilot Cadamosto refers to this method.[20] When Prince Henry died in 1460, these principles were already established and his exploratory ventures were embraced by his successors.

As the Portuguese approached the equator in 1471, they confronted a new challenge… the North Star was no longer visible on the horizon. Consequently, the development of a new method became crucial so that sailors could determine their latitude as they pushed into the southern hemisphere. In the early 1480s, King João II (1455-1495) assembled the *Junta dos Matemáticos*, a group of mathematicians, cartographers and astronomers, in order to solve this new problem.[21] Among the most renowned figures in this commission were José Vizinho, former student of the eminent Jewish astronomer Abraham Zacuto, author of the *Almanach Perpetuum*, and Martin Behaim, of the school of the prominent German mathematician and astronomer Johannes Müller, more widely known as Regiomontanus.[22] The solution provided by the *junta* was *The Regiment of the Sun*, a manual that contained tables indicating the sun's declination for every day of the year.[23] This enabled mariners to determine their approximate latitude by measuring the elevation of the sun at noon and making necessary adjustments.

Solar declination tables were not new to astronomy. In 1252, the court of Castilian King Alfonso X created the *Tabule Astronomice*, a manuscript that contained this information. Regiomontanus wrote a similar work, the *Ephemerides*, in 1475. Nonetheless, the document that served as a model for the tables developed by the *Junta dos Matemáticos* was the *Almanach Perpetuum* authored by Zacuto, former instructor of José Vizinho.[24] Although this knowledge had been available to an educated elite for centuries, it was not until the late fifteenth century that it became available to the ordinary pilot in a way that allowed for its application at sea.

The final document produced by the *junta* was the *Regimento do Estrolabio e do Quadrante*, the earliest navigation manual published in Europe.[25] In addition to the solar declination tables, the guide contained instructions for calculating latitude based on the sun's meridian altitude, seventeen examples for their application, rules for the use of the North Star, a list of sixty locations along Africa's west coast with their respective *alturas*, directions on how to plot a vessel's track and a copy of the *Tractatus Sphaera Mundi*, an astronomical treatise by Johannes de Sacrobosco, an English mathematician and astronomer who lived during the thirteenth century and about whom little else is known with certainty.[26]

Another method for calculating latitude in the southern hemisphere was developed by the Portuguese around the year 1500. It consisted on the observation of a star that, like Polaris in the northern hemisphere, was close to the south celestial pole. They called the star the *Estrela do Sul* and the set of rules developed for its use the *Regimento da Altura do Polo pelo Cruzeiro do Sul*.[27]

In this way, the Portuguese established the principles of modern navigation that only during the twentieth century, with the advent of satellite navigation and the Global Positioning System (GPS), became obsolete. For all this theory to be applied at sea, the Portuguese court adopted instruments that had for centuries been used by astronomers and adapted them so that the average ship pilot could utilize them. Among them was the astrolabe, which became the most popular by the turn of the sixteenth century.

This work builds on a tradition of research on the sea or mariner's astrolabe that began in Portugal in the early twentieth century with the works of Luciano Pereira da Silva. The first section presents the story of the Rincón Astrolabe Shipwreck, a wreck site discovered in 1986 by a local fisherman off Puerto Rico's west coast. This discussion is relevant because it immerses the reader in the middle of a fierce legal battle for the ownership of a submerged cultural resource. Furthermore, since it was the first time this happened in Puerto Rico's recent history, it established the precedent on which future court decisions on similar cases are likely to be based. The second section deals with the astrolabe, the artifact perceived by the public to be the site's most relevant find, and the one that ultimately drove the wreck salvors into court. In it, the historical background in which the mariner's astrolabe came into being is presented. The third section discusses the archaeology of the sea astrolabe from the early twentieth century, when only a handful of samples were known to exist, to the present day, when the count approaches ninety. The last section comprises a catalog of sixteen of these instruments, all of which were found after 1988, when the last comprehensive work on the nautical astrolabe was published. Some of these astrolabes have already been presented in earlier publications. However, this represents the first effort to gather them in a single source and language, making the information more readily available to the researcher. Seven unpublished samples are presented.

Although this work is presented as a thesis for a degree in Nautical Archaeology, it does not deal with ships. Instead, it is about the instruments and methods used by their pilots in their attempts to, sometimes more successfully than others, navigate them safely and efficiently across the ocean sea. This work presents the results of five years of research during which the author expended great energy towards gathering as much information as time and geographic limitations allowed. It is hoped that this effort contributes to the tradition of pristine scholarship that has for decades been devoted to the study of the mariner's astrolabe.

THE RINCÓN ASTROLABE SHIPWRECK

The Story[28]

Rincón is a small municipality on the west coast of Puerto Rico. For decades, it has been popular among tourists and locals. The town's reputation as a paradisiacal enclave increased after the late 1960s, when its name resonated internationally as one of the world's best surfing locations. Its charm and beauty make it a place hard to leave behind. It is common to walk into one of Rincón's bars and find someone who arrived twenty years earlier for a week of good surfing and never returned home. This has given the place a unique atmosphere, with the largest population of expatriates in the island, mainly from the United States. The town is also a favorite among locals, who crowd it on weekends to enjoy the nice beaches and the luscious seafood restaurants. Rincón is known traditionally as "the town of beautiful sunsets." Its shoreline affords a breathtaking view of the Mona Passage, providing the perfect setting to enjoy lunch on a Sunday afternoon or simply to linger and relax. Rincón has many attributes that stand out from the typical town in Puerto Rico. In 1987, one more element was added to its magic, when Rincón became the place where an astrolabe was found.

Richard Fitzgerald is one of those Americans who went to Rincón for a short visit three decades ago and never found his way out. A native of Braintree, Massachusetts, he was living in Cooperstown, New York, when he arrived in Puerto Rico in 1970. His brother, a professional photographer who went to Rincón in 1968 to document the World Amateur Surfing Championship, invited him. Although his sibling eventually returned to the United States, Fitzgerald decided that the place was too nice to leave permanently. Therefore, he began to spend six months in Puerto Rico and six months in Cooperstown, and finally he just stayed on the island. Sixteen years later he was still living in Rincón. During that time, he made a living as a painter, bartender and fisherman. The latter occupation made him an able seaman, with a reasonable knowledge of the town's coastal area. In 1986, a couple visiting from Cooperstown asked him to teach them how to SCUBA dive. They agreed to meet on the afternoon of December 30. He could have never imagined what fate had arranged for him that day.

Fitzgerald arranged the diving equipment in a small boat he borrowed from a friend. As the trio cruised along the coast of Black Eagle Beach, the boat's outboard engine suddenly experienced mechanical problems. Being the only skilled seaman onboard, Fitzgerald put on his snorkeling gear and jumped in the water. They were approximately 180 meters from the coast and the water was clear. While working on the engine, he noticed some uncommon dark formations on the seabed. The depth was about four meters, so he decided to go down and check. At the bottom, he hand-fanned what seemed to be a mound of buried rocks. Unable to stay down for long, Fitzgerald resurfaced, asked for his SCUBA gear, returned to the bottom and tried to make sense of these odd formations. Especially remarkable were some plants growing in a straight-line pattern for a length of about two meters. He kept removing sand and suddenly realized that the plants were growing on top of cannon. The "rock piles" he was uncovering were ship's ballast. He had discovered a shipwreck. Fitzgerald returned to the boat and told his friends, who went snorkeling at the site. Afterwards, he cautiously fixed the wreck's location using landmarks and returned to the shore.

The first person in Rincón to learn about Fitzgerald's discovery was his friend Bill Embree, owner of the boat Fitzgerald borrowed and of a restaurant by Black Eagle Beach. The next day both men returned to the site and began to salvage artifacts, mostly concretions and pottery shards. The secret broke open that evening, when Fitzgerald and Embree went out to celebrate their find. By the end of the night, many persons in town knew of what laid below the sand near Black Eagle Beach. Days later Mikal Woods, a friend of both Fitzgerald and Embree, joined the team.[29] His father soon followed. For the next few months, the quartet dived at the site frequently and the recovery efforts continued. Among the most remarkable finds during that period were a harquebus and a pewter plate. The plate still bore its maker's mark, which research later revealed to be that of Nicholas Kelk, an English pewter maker who was active during the second half of the seventeenth century (**Fig. 1**).[30] They also salvaged numerous concretions and pottery shards. Some of the artifacts were stored in fresh water at Embree's restaurant, and some were left out in the open.

Fig. 1. Nicholas Kelk maker's mark. From the touch-plate of the Worshipful Company of Pewterers, with marks dated *c.* 1680 (after Howard Cotterell's *Old Pewter: Its Makers and Marks*)

Jaime Braulio, a friend of Fitzgerald, was a diving instructor in Mayaguez, the city closest to Rincón. He was a skillful diver who owned a dive shop, a boat and underwater lifting equipment. Thus, Fitzgerald concluded he would be a great asset to the group. When Braulio was informed of the wreck, he told Fitzgerald that it would be helpful to involve his acquaintance Arturo Gandía, a retired businessman from San Juan who had a keen interest in maritime history. Gandía was the founder of the now extinct Puerto Rican Society for Maritime History and Underwater Archaeology.[31] Fitzgerald agreed, and a few days later Braulio called Gandía. Thrilled by the story, Gandía contacted Harry Hauck, a diving instructor in Fort Buchanan, Bayamón, who often had Gandía as a guest speaker in his lectures.[32] Hauck, who frequently organized diving trips for his students, thought that the wreck site would provide an exciting experience for his class. Gandía also called his friend Carlos Rivera, a television commercial producer and amateur SCUBA diver. Rivera owned an underwater video camera and a metal detector, which Gandía reasoned would be very useful in the salvage operations.

That is how one morning in the spring of 1987 Fitzgerald, Embree, Woods, his father, Braulio, Gandía, Rivera and Hauck with around twelve of his students gathered at Embree's restaurant, whence they went to dive at the shipwreck site. Although the day proved fruitful, with the group sighting the ship's anchor, cannon and scattered ballast stones, Fitzgerald and Woods became upset when Hauck's students removed artifacts from the site. They expressed their concern to Gandía and Hauck, and told them that big crowds were no longer welcome. Both men apologized and promised that it would not happen again.[33]

Gandía, Hauck and Rivera did not return to the site until the summer. On June 27, they went to Rincón with a boat Rivera had recently acquired, books on underwater exploration and two metal detectors. They spent the night in a room Embree provided and the following day they went to the site, together with Fitzgerald, Woods and Embree. The metal detectors proved very useful. As the divers probed the bottom, they found an additional harquebus and another pewter plate. However, the discovery that sent the whole affair to another level was made when Rivera and Hauck went searching to the southeastern corner of the wreck. Woods suggested this area, since artifacts seemingly became more abundant as they dived southeast from the anchor. As Hauck and Rivera surveyed the zone, the metal detector revealed an anomaly. Following, Hauck hand-fanned through approximately thirty centimeters of sand, under which he uncovered a wheel-shaped metal artifact. Neither Hauck nor Rivera knew what it was, nor did Fitzgerald or Woods. It was only when the object was taken to the beach, where Gandía waited, that he identified it as a mariner's astrolabe.[34] Gandía explained to the group the importance of the find. At the time, only about sixty sea astrolabes were known to exist. Everyone became utterly excited. That night, in the midst of the celebration, Hauck expressed that it was advisable to keep the find secret until they decided what to do with the instrument. At that point, the hitherto friendly venture showed the first sign of fracture. The following day the team returned to the site, where Rivera made a video. That afternoon Gandía, Hauck and Rivera returned to San Juan.

It is difficult to establish what happened from late June until mid August 1987, when the government intervened. However, it is certain that, once the astrolabe was found, the group members thought of it, and of the whole wreck, as a potential source of great revenue. The exception was Gandía, who from the beginning expressed that his only interest was to assist in the operation. In July, Gandía, Hauck and Rivera paid a third visit to the site. Rivera again brought his boat, this time with a prop wash blaster he designed. It was used with limited success. According to Woods, since the boat was not properly anchored, it moved from side to side every time the blaster was activated. Versions vary on what was recovered that day. Some claim that nothing, while others assert that several artifacts.[35] That afternoon the astrolabe emerged once more as the critical issue. The matter revolved around one question… what should be done with it? It is impossible to ascertain who said what. Two sources agree that, between Rivera's second and third visit to Rincón, he held conversations with Fitzgerald, apparently without Hauck's and Gandía's knowledge. According to Fitzgerald, Hauck was the first person to propose selling the instrument in Florida, where a potential buyer was willing to pay nine thousand dollars. Rivera affirms that the idea to take the astrolabe off the island first came from Fitzgerald. Whatever the case, the argument ultimately focused on whether the astrolabe would be sold overseas or given to the Puerto Rican government so it could remain in the island. As the dispute grew, Rivera threatened that, if the group insisted on exporting the instrument, he would contact the local authorities. The others replied that, in such case, they could declare that the astrolabe had been stolen and take it off the island. The argument reached its climax on 4 August 1987, when Rivera went to a lawyer and prepared a sworn statement. The following day the attorney contacted the Institute of Puerto Rican Culture (IPRC) and exposed the whole affair. The institute immediately got the state court to order that salvage cease. With this action, the story of the Rincón Astrolabe Shipwreck entered a new stage.

Law 10, enacted on 7 August 1987, is the law through which Puerto Rico's submerged and coastal cultural resources are managed. Remarkably, it was not motivated by the Rincón case, but by an approach that the renowned treasure hunter Mel Fisher made to the Puerto Rican authorities in 1986, expressing his desire to conduct explorations on the east coast of the island. This raised the concern of Senator Velda González, who made it her cause to prevent the looting of the island's underwater archaeological sites. She authored the law and had it approved the following year. During late August 1987, Rivera and Fitzgerald argued on the effect this could have on their venture. By those days Elías López Sobá, then director of the IPRC, filed suit against Fitzgerald, Embree and Woods in Aguadilla's Superior Court.[36] Although Law 10 is supposedly non-retroactive, it was used to reclaim the artifacts from the salvors.[37]

The state of affairs at that stage was nicely summarized in a newspaper article published on 18 September 1987.[38] The first paragraph reads: “A 17th century [sic] astrolabe and other historical artifacts recovered from a sunken galleon ‘definitely’ belong to the government, says Elías López Sobá, executive director of the Institute of Puerto Rican Culture. However, another institute official indicated that ownership probably would have to be decided by the courts.” According to the report, other artifacts recovered from the site included “muskets, carpenter tools, pewter plates and a 6-foot-long cannon…” The first inventory was made on 22 November 1988 by archaeologist Eugenio Barnes of the IPRC.[39] Although it was established early on that the salvors had no right of ownership over their find, the government understood, as is indicated in Law 10, that they had the right to compensation. According to Pedro Salazar, assistant director of the IPRC, the applicability of the law was doubted at the time. The last paragraph of the article was a forecast of what was coming. Part of it read: “Hauck and Rivera… said they, not Fitzgerald, actually discovered the astrolabe, though both admitted that Fitzgerald and Embree had asked them to assist in the diving. However, no contract or arrangement of any kind was signed. Hauck and Rivera, on one side, and Fitzgerald and Embree, on the other, are contesting ownership of the astrolabe.”

Realizing that their chances against the IPRC were slim, the Rincón team decided to take their struggle to the federal forum.[40] They appeared in Puerto Rico’s federal court on 9 February 1988. Their argument was that state laws should not apply, since the case was one of admiralty, a matter in which local authorities have no jurisdiction. They further contended that, since it was not practical for the federal court to assume responsibility, they should be declared "exclusive custodians" of the shipwreck, all the salvaged artifacts and those still buried at the site. According to the trio, they had the abilities, facilities and knowledge to store all the objects in a safe place.[41] The suit mentioned that, even though the astrolabe was given to the IPRC, any other artifacts recovered from the site would be handed to the Federal Court, which would serve as the official curator. The day after Fitzgerald's group action, Hauck and Rivera appeared before the same magistrate with the same claim. The IPRC followed, asking the court to reject both parties' motions and recognize the jurisdiction of the state court. On February 13, the judge ruled in favor of the IPRC, denying the finders custody of the wreck and any of its artifacts. The issue of jurisdiction was solved weeks later, when a federal judge decided that it corresponded the state court to resolve the case.

Back in state court, and perhaps fearing the adverse effects that the non-retroactivity of Law 10 could have on their position, the IPRC got the magistrate to declare the artifacts recovered from the shipwreck the property of Puerto Rico's government. Furthermore, the judge ruled that the government's custodian for all such finds would be the IPRC.[42] The ruling was based on the Spanish Law of Ports of 1880, which was extended to Puerto Rico in 1886. According to the court's verdict, it only remained for the finders to submit claims for what they considered to be fair compensation. On what seems as a desperate measure, Fitzgerald, Embree and Woods took their claim to Puerto Rico's Supreme Court. However, this forum stood besides the state court's decision. Although at that point the dispute was supposedly solved, it subsequently entered a seemingly endless process of interpretation. The argument circles around three points: what is fair compensation? Does it include the value of the artifacts that are still underwater? Who is going to pay the finders? By the summer of 2005, the case was still pending resolution in Aguadilla's Superior Court.

The Site

The shipwreck whose story was just presented is located approximately 180 meters from *Playa Ensenada* (Cove Beach), known as Black Eagle Beach to the English speaking population of Rincón. The approximate coordinates for the site are N 18° 20' 39" and W 067° 15' 40" (**Fig. 2**). Due to the tides and currents, the depth at the site fluctuates between four and six meters. The currents constantly move sand, so while sometimes the shipwreck is almost exposed, it is usually covered by a layer over one meter thick. Even though no methodical plan was developed while the site was being intruded, later a drawing was made of where the artifacts approximately lied (**Fig. 3**). Although not to scale, the illustration provides context.

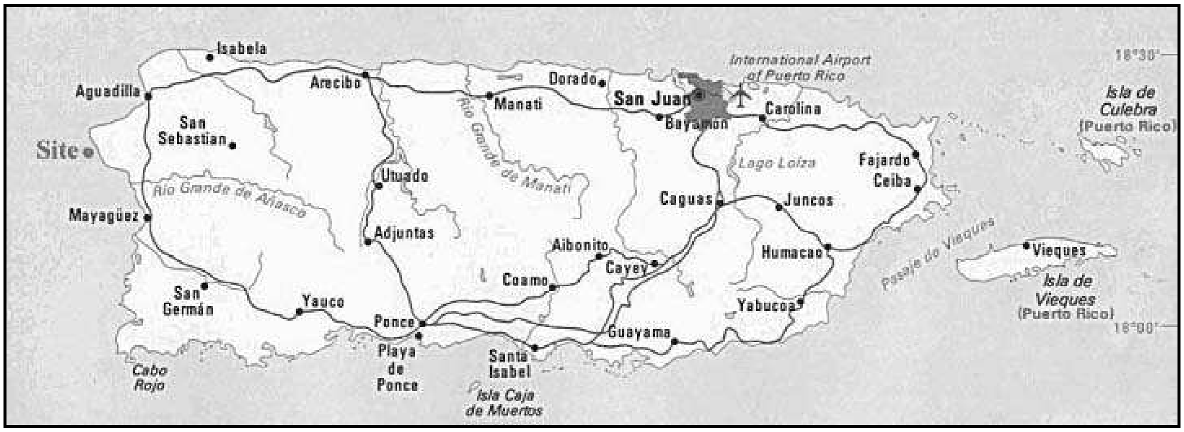


Fig. 2. Map of Puerto Rico showing the approximate location of the wreck site.

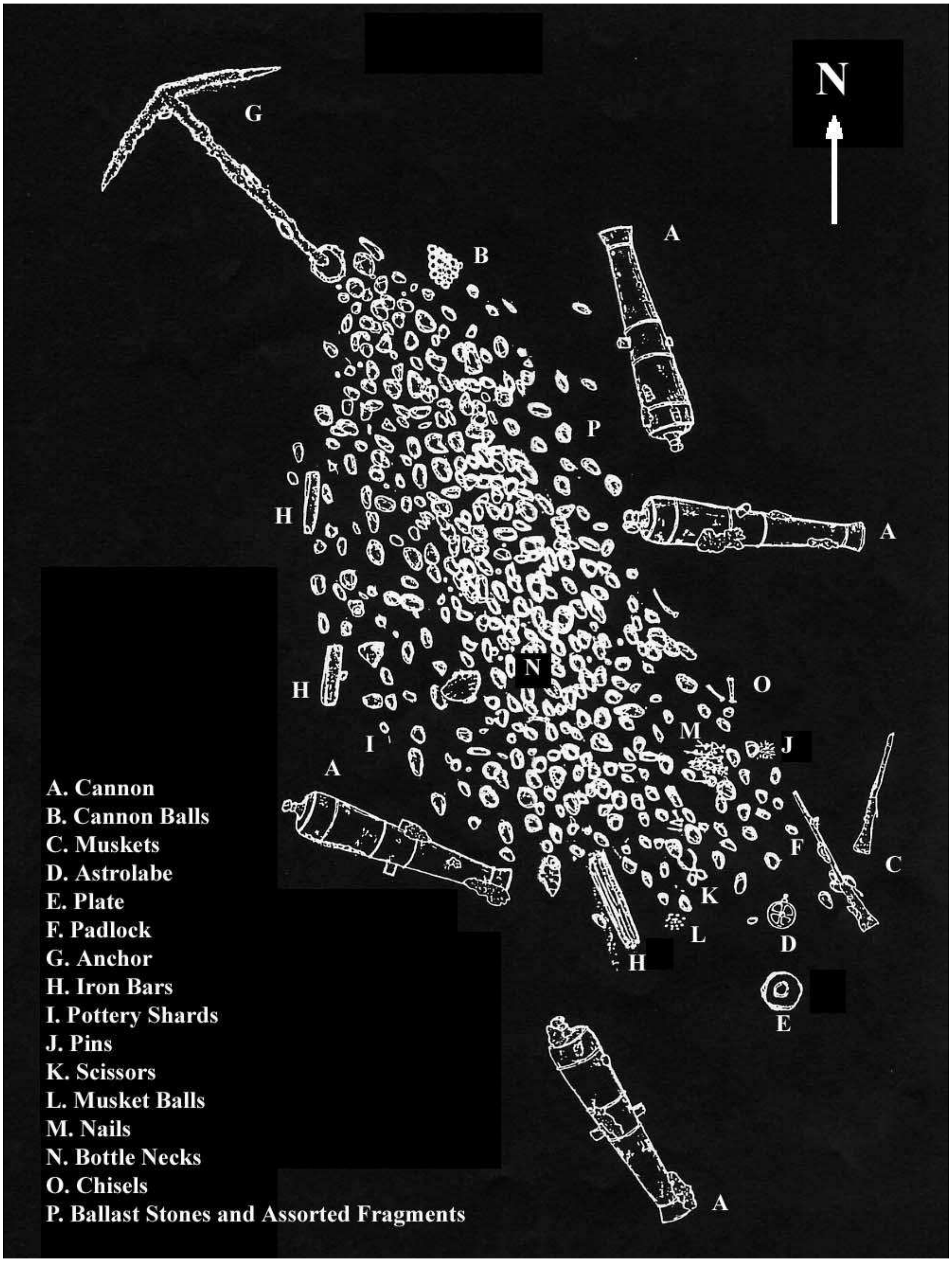


Fig. 3. The wreck site. (Drawing by Richard Fontánez of Puerto Rico's Council for Underwater Archaeology)

THE SEA OR MARINER'S ASTROLABE

Of all the objects recovered from the wrecksite, the astrolabe caused the most exhilaration among the finders. Later on, the public became interested in the case. This is easily justified. Primarily, at the time of the find, very few people in Puerto Rico knew what an astrolabe was. The news that suddenly appeared in the newspapers grabbed the attention of many. Second, the artifact's almost perfect state of preservation made it hard to believe it was almost four hundred years old. Additionally, after the case appeared in the media, some people got the impression that the astrolabe could have an enormous monetary value. Whatever the reasons, it goes without question that the instrument was one of the best preserved in the world.

In this section, an analysis of the artifact will be presented. However, it seems suitable to introduce the discussion with a description of the most popular navigation instruments used by European seamen during the Late Middle Ages. This will allow the reader to attain a better understanding of the setting in which the nautical astrolabe emerged and its role in seafaring from the late fifteenth to the early eighteenth centuries.

Navigation Instruments of Late Medieval Europe

To implement the navigation methods that they developed during the fifteenth century, Portuguese mariners were provided with scientific instruments that had been traditionally used on land for various purposes. The first of these devices was the quadrant. The quadrant used by sea pilots during the fifteenth century was an adaptation of an instrument created by Islamic astronomers during the Middle Ages.[43] Used as a sundial, the Arab quadrant was engraved with a complex pattern of lines and curves based on a stereographic projection of the celestial sphere. All of these were superfluous to the navigator, who only needed to measure the elevation of a heavenly body. Furthermore, it was desirable to eliminate any features that could confuse the mariner, usually a simple man. Therefore, the quadrant used by Portuguese seafarers was an unsophisticated device.

As its name suggests, the mariner's quadrant consisted of a plate shaped as a quarter of a circle. It was generally made of brass, but wood was also used.[44] Its radius fluctuated between fifteen and twenty centimeters. The arc was engraved with an angular scale ranging from zero to ninety degrees. A plumb line was attached to the vertex of the right angle, with a weight tied to its other end. The cord was slightly longer than the radius of the quadrant, so that the weight would not interfere when readings were being made. Two small pierced rectangular plates were attached to one of the straight sides of the instrument. These served as a sight (**Fig. 4**). Some quadrants had two holes of different sizes pierced through each sighting plate; the smaller for solar, the larger for stellar observations.[45] The mariner's quadrant was widely used by 1450.[46]

To determine the elevation of a celestial body, the pilot held the quadrant vertically, with the sighting plates upwards. Looking through them, he turned the instrument until he could see the desired star. At this point, the cord intercepted the scale at the angle between the horizon and the star. This was the altitude or *altura*. Then, applying the pertinent rules, the mariner converted this measure to degrees of latitude. It was common for navigators to mark the scales on their quadrants at the *altura* of important places.

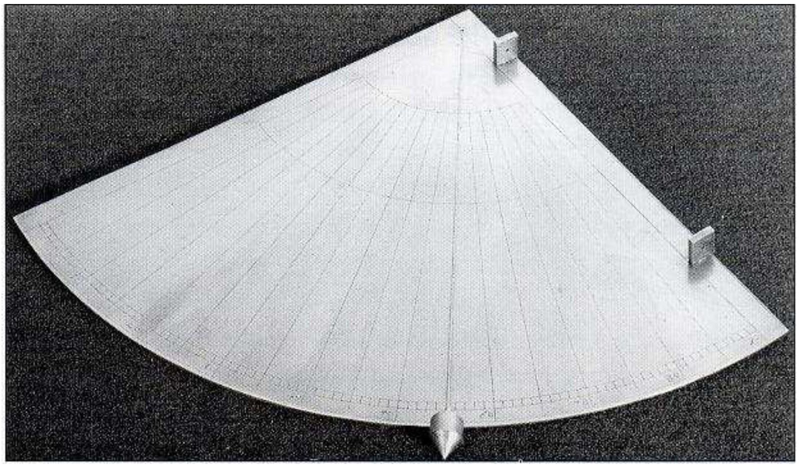


Fig. 4. A quadrant (*c.* 1600) showing the typical features of the instrument. (After Peter Ifland's *Taking the Stars: Celestial Navigation from Argonauts to Astronauts*)

As Diego García de Palacio indicates in his *Instrucción Náutica para Navegar* (1587), mariners also used the quadrant to make solar observations.[47] For this purpose, the sailor stood facing the sun at noon, and then turned the instrument until the sunlight passed through both holes on the sighting plates. At this point, the observer read the altitude on the scale. Referring to the declination tables and performing the required calculations, navigators were able to have a reasonably precise idea of their latitude. However, the mariner's quadrant was primarily used to measure the elevation of the polestar.[48]

Although the quadrant proved practical, its use at sea presented problems. Mainly, the constant motion on a ship's deck made it hard to determine when the plummet line was marking the elevation angle. Consequently, if accurate readings were desired, the pilot had to go ashore. Such a deed usually involved potential hazards.[49] In spite of this, the quadrant remained popular among navigators for centuries. No mariner's quadrant from the fifteenth or early sixteenth century has been preserved.[50]

Parallel to the quadrant, Portuguese seamen of the late fifteenth century used an instrument called the sea or mariner's astrolabe to aid them in calculating latitude. This was a simplification of a device used by the Arabs in medieval times, the planispheric astrolabe, arguably one of the oldest scientific instruments known.[51] The Greeks knew the principles of stereographic projection on which this device worked by the second century B.C. A description of the planispheric astrolabe, as the Muslims built it, appears in a document from A.D. 375.[52] The Arabs introduced the instrument to Europe during the tenth century,[53] and by the thirteenth century it became an integral tool in horological and astronomical studies, as well as surveying and measuring the altitude of heavenly bodies. This was the mechanism late medieval seafarers adopted.

It is hard to ascertain when the astrolabe was first used in navigation. There is evidence of such instruments being carried in ships during the fourteenth century. In 1402, Jean de Béthencourt, a French explorer who that year began the conquest of the Canary Islands, mentions that he sailed there directly from Cádiz aided by a compass and an *astrolabium*.[54] However, it is likely that these were planispheric astrolabes used by astrologers traveling in the ships. It is improbable that the common seafarer could understand the complex arrangement of discs and curves. It is also unlikely that such an expensive device would have been kept in a vessel. Written evidence suggests that planispheric astrolabes were precious possessions that their owners preserved with great zeal.[55]

Evidence for the use of a mariner's astrolabe was first recorded in 1481, during a Portuguese expedition along the west coast of Africa led by Diogo d'Azambuja.[56] The instrument was also used in 1488 by Bartholomew Dias, in 1492 by Christopher Columbus, in 1497 by Vasco de Gama, in 1500 by Álvares Cabral and in 1519 by Ferdinand Magellan during the first circumnavigation of the globe.[57] Sources present evidence that the nautical astrolabe became the favorite instrument of most navigators. In 1492, Martin Behaim, who that year built one of the most famous medieval terrestrial globes, referring to the Atlantic Ocean wrote: "Those who navigate this sea must do so aided by the astrolabe." In 1500, Álvares Cabral referred to the device as being better than the quadrant or any other instrument.[58]

The back side of some planispheric astrolabes shows the instrument's features that were adopted by navigators. The first mariner's astrolabes consisted of a solid disc with an angular scale engraved along its circumference. A hinged ring on top of the disc served as a means by which the instrument could be suspended. In order to measure altitude, a pivoting alidade with two widely spaced sights was attached to the astrolabe's center. The earliest known illustration of one of these instruments appears in 1529 in a set of nautical charts drawn by Diego Ribeiro, who had in 1523 been appointed First Cosmographer of the Spanish *Casa de Contratación*.[59] Although some scholars argue that the instrument depicted by Ribeiro is a planispheric astrolabe, the fact that it was drawn in a nautical chart by a recognized cosmographer suggests that such devices were used at sea. A mariner's astrolabe of around 1500, kept in the *Casa de Colón* museum in the Canary Islands, shows some resemblance to the one depicted in Ribeiro's chart (**Fig. 5**).[60] Most of these instruments were made of brass, but some were made of wood. This was the case with the astrolabe used by Vasco de Gama when he reached the Bay of St. Helen in 1497. Like the quadrant, this instrument was taken ashore to make precise observations. Its diameter was approximately sixty centimeters.[61]

These devices must have been affected by the wind too. That is why, during the first decades of the sixteenth century, the mariner's astrolabe underwent substantial changes. As most of the archaeological evidence suggests, the modified instrument consisted of a thick brass or copper wheel connected to a hub by four spokes. This rendered it more stable in windy conditions. The astrolabe's diameter decreased considerably, without a standard dimension being adopted.[62] The alidade was adjoined to the hub by an axis pin secured by a wedge run through a slot. By the late sixteenth century, a bolt with a threaded wing nut replaced this mechanism.[63] The distance between the sights on the alidade also decreased. Although this reduced the precision of the readings, it made the instrument's use less difficult on the deck of a moving ship.[64]

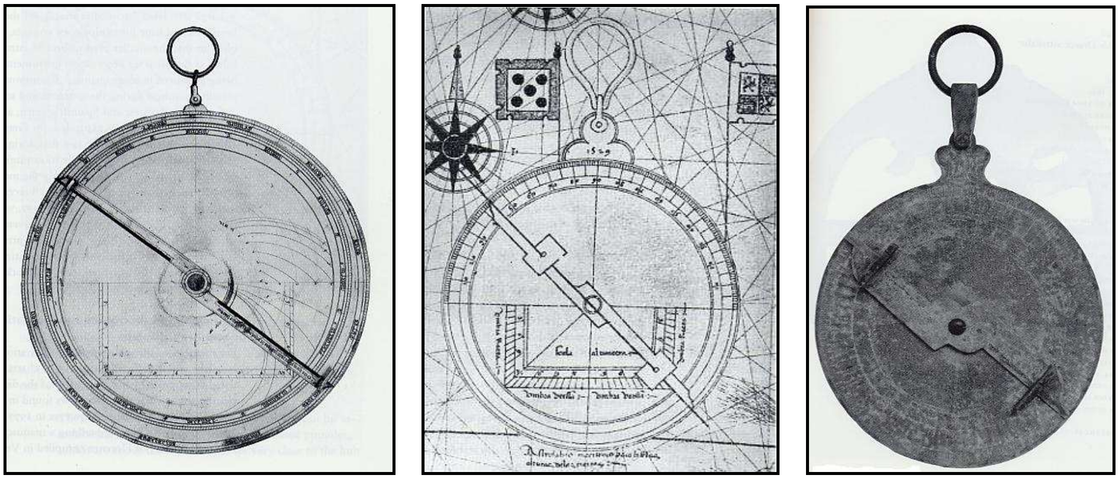


Fig. 5. The mariner's astrolabe shown as an adaptation of the planispheric astrolabe. The figure on the left shows the back side of an Islamic planispheric astrolabe (*c.* 1400). The astrolabe depicted at the center was drawn by Diego Ribeiro on a nautical chart in 1529. To the right, a mariner's astrolabe (*c.* 1500) found in the Canary Islands. (After Alan Stimson's *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*)

Most of these astrolabes had the scale engraved on their two upper quadrants. The suspension ring on top of the limb was kept. To counteract further the effects of the wind, the bottom spoke was shaped so that it would provide additional ballast. A manuscript drawing from 1517 is hitherto the oldest known representation of a cast-wheel type nautical astrolabe (**Fig. 6**). The fact that this illustration predates that of Ribeiro by twelve years suggests that, at some point in the early sixteenth century, a transition was taking place from the disc to the sturdier cast-wheel astrolabe, during which both types were used. The earliest known cast-wheel astrolabe, the Palermo, was made in Portugal in 1540. Unfortunately, it was lost during World War II.[65]

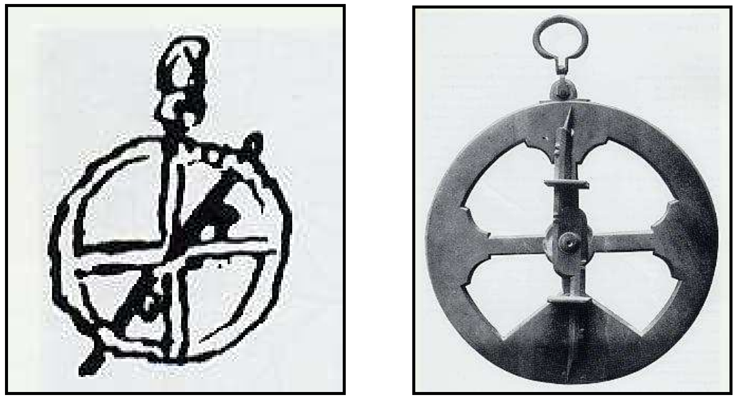
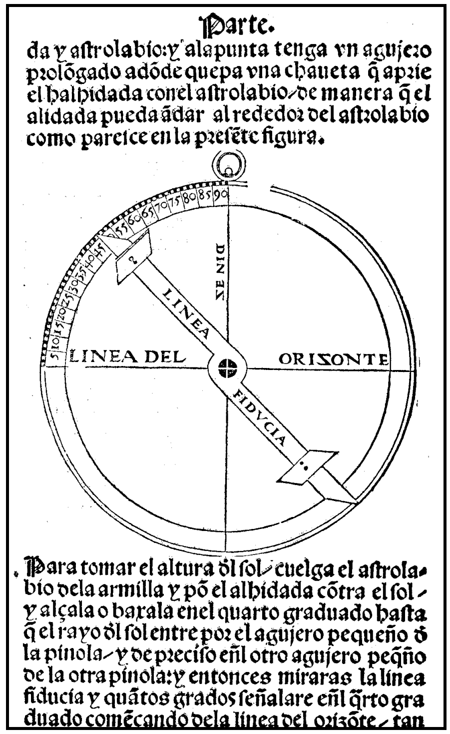


Fig. 6. The mariner's astrolabe as it became popular during the early sixteenth century. To the left, a mariner's astrolabe depicted in a manuscript from 1517. The picture to the right is of the now disappeared Palermo astrolabe (1540). (After Alan Stimson's *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*)

A vivid description on how to build a nautical astrolabe appears in Martín Cortés' *Breve Compendio de la Sphera y de la Arte de Navegar*. Written in 1545 and published in 1551, this is one of the earliest navigation manuals published in Spain. Curiously, the process he describes is for the construction of a disc-type astrolabe. The archaeological evidence for instruments manufactured between 1540 and 1550 suggests that the cast-wheel astrolabe was predominant then. Both the text and the illustration in the manual indicate that, as with the quadrant, the astrolabe had two orifices in each sighting plate… the smaller to measure the altitude of the sun, the larger for measuring the elevation of the stars (**Fig. 7**).[66]



Parte.
da y astrolabio: y ala punta tenga vn agujero
prolõgado adõde quepa vna chaueta q̃ aprie
el halhidada conel astrolabio/de manera q̃ el
alidada pueda ãdar al rededor del astrolabio
como parece en la presẽte figura.

Para tomar el altura dl sol/cuelga el astrola-
bio dela armilla y põ el alhidada cõtra el sol/
y alçala o baxala enel quarto graduado hasta
q̃ el rayo dl sol entre por el agujero pequeño d
la pinola/y de preciso eñl otro agujero peq̃ño
de la otra pinola: y entonces miraras la linea
fiducia y quãtos grados señalare eñl q̃rto gra
duado comẽcando dela linea del orizõte/tan

Fig. 7. A mariner's astrolabe as depicted by Martín Cortés in 1545. (After Martín Cortés' *Breve Compendio de la Sphera y de la Arte de Navegar*)

Cortés also provides instructions on how to use the astrolabe, but those given by García de Palacio in his *Instrucción Náutica para Navegar* (1587) are more comprehensive. García recommends that the pilot measuring the altitude of the sun must do so at noon, close to the main mast, where the ship is more stable. Then, hanging the astrolabe by its ring with the index finger of the right hand, the observer must stand facing the sun. Next, the alidade should be turned until the sunlight goes through the small holes on the sighting plates and is projected on the ship's deck. At this point, the tip of the alidade is indicating the altitude.[67] Since it was hard in a ship to determine when it was noon exactly, the observer had to arrive early on deck and measure until the sun began to decline.[68] After this explanation, García gives various examples on how to convert altitude to latitude based on solar declination tables and the position of the shadow of the observer. The reader is encouraged to consult the original text, since it provides an elucidating description on how the sea astrolabe was used.

During the sixteenth century, the mariner's astrolabe underwent additional modifications. The most significant were the inversion of the scale and the introduction of the wedge-shaped astrolabe. Originally, since the instrument was meant to measure altitude, the scale began at zero on the horizontal and ended at ninety on the top of the rim. This meant that, when the navigator had to convert his reading to degrees of latitude, a necessary step was to subtract the measured angle from ninety. To avoid this, by the mid sixteenth century Portuguese instrument makers began to engrave the scales on their astrolabes with ninety on the horizontal and decreasing to zero on the top of the rim.[69] Instead of measuring the elevation of the sun, the pilots using these instruments were measuring its angular distance from their zenith.

Another modification made to the astrolabe by the mid sixteenth century was to increase the thickness of the lower portion of the wheel.[70] The intention was to make the instrument heavier at the bottom, so that it would be more stable. In his publication of 1988, Alan Stimson indicates that the Spaniards introduced this feature sometime around 1550. He also suggests that such a device would have been impractical, since its proportions deflected its plane from the vertical, introducing unacceptable imprecisions in the observations. He concludes that this may have been counteracted by using a heavier alidade and that this feature was abandoned early in the seventeenth century. It is, however, remarkable that the Spanish adopted this practice in the mid sixteenth century, given that in 1545 Martín Cortés recorded that, when building an astrolabe, the maker should "clean and flatten the sheet (of brass) on both sides, so that it is all of the same thickness, and it is not heavier on one side than on the other."[71]

Although the mariner's astrolabe proved better than the quadrant, it was not without its flaws. Its reduced diameter and the proximity of its sighting vanes compromised its precision. Errors of four and five degrees were common.[72] The archaeological evidence suggests that multiple instruments were usually carried in a ship.[73] It is possible that various astrolabes were used simultaneously in order to corroborate precision. Even though the astrolabe was used until the late seventeenth century,[74] by the mid sixteenth century some mariners preferred using the cross-staff.

Also known as fore-staff or *balestilha*, the cross-staff was an instrument developed by the Arabs during the Middle Ages for surveying purposes. The renowned Iranian physician Avicenna (980-1037) first presented it in the eleventh century.[75] Its earliest mention in Europe dates to 1342, when Levi ben Gerson described it in his *Traité de Trigonometrié*.[76] Like the two devices previously discussed, navigators used the cross-staff to measure the altitude of a heavenly body.

Most sources agree that the cross-staff was first used in navigation by the late fifteenth century. The Portuguese João de Lisboa mentioned it in a maritime document dated ante 1520.[77] The instrument consisted of a wooden shaft with a square cross-section. Its length ranged between seventy-six and ninety-two centimeters.[78] A pierced wooden board was placed perpendicular to the staff, free to slide along its length (**Fig. 8**). One of the sides of the shaft was engraved with a scale in degrees.

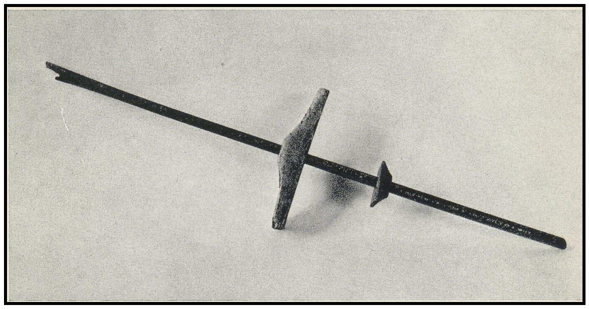


Fig. 8. The earliest extant nautical cross-staff (*c.* 1590). (After Francis Maddison's *Medieval Scientific Instruments and the Development of Navigational Instruments in the XV^th^ and XVI^th^ Centuries*)

To use the cross-staff, the navigator placed the extremity of the shaft on his cheekbone, right below the eye, so that the crosspiece was in a vertical position. He would then slide the crosspiece along the staff until its low end was on the horizon and the high one on the center of the celestial body (**Fig. 9**). The altitude was then read from the staff.

With its light weight, simple construction and low cost, the cross-staff rapidly became the favorite instrument of many pilots. Its larger scale also made it more accurate than the quadrant and the astrolabe, with readings being precise down to twelve minutes of arc.[79] During the sixteenth century, additional crosspieces of different lengths were added so that a greater range of altitudes could be measured. To enable their use, each side of the staff was engraved with a different scale. Once more, García de Palacio and Martín Cortés give descriptions on the making of a cross-staff (**Fig. 10**).

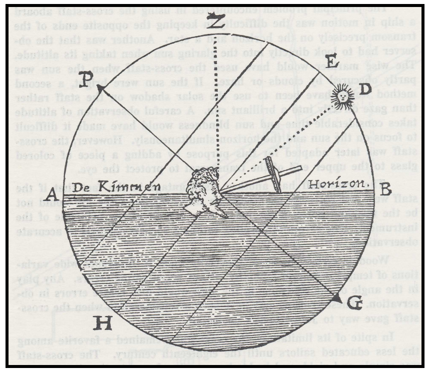
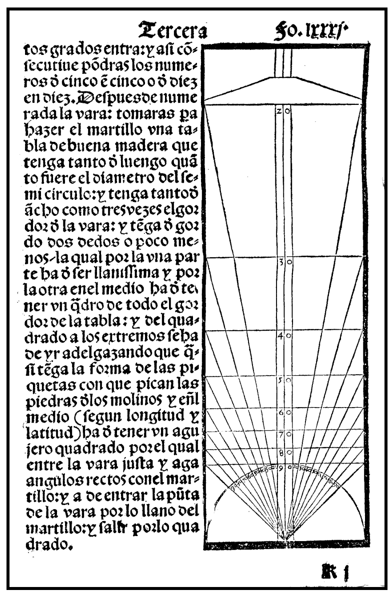


Fig. 9. Using a cross-staff. (After Duane Cline's *Navigation in the Age of Discovery: An Introduction*)


Tercera
fo. lxxx
tos grados entra: y aſi cõ-
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ros ꝺ cinco ẽ cinco o ꝺ diez
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rada la vara: tomaras pa
hazer el martillo vna ta-
bla de buena madera que
tenga tanto ꝺ luengo quã
to fuere el diametro del ſe-
mi circulo: y tenga tanto ꝺ
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doꝛ ꝺ la vara: y tẽga ꝺ goꝛ
do dos dedos o poco me-
nos/ la qual poꝛ la vna par
te ha ꝺ ſer llaniſſima y poꝛ
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quetas con que pican las
piedras ꝺlos molinos y eñl
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latitud) ha ꝺ tener vn agu
jero quadrado poꝛ el qual
entre la vara juſta y aga
angulos rectos con el mar-
tillo: y a de entrar la pũta
de la vara poꝛ lo llano del
martillo: y ſalir poꝛ lo qua
drado.

Fig. 10. The construction of a cross-staff, as described by Martín Cortés (1545). (After Martín Cortés' *Breve Compendio de la Sphera y de la Arte de Navegar*)

As with the two instruments previously discussed, the cross-staff presented problems for the user. It was difficult on the deck of a sailing vessel to maintain one extremity of the transom on the horizon and the other on the star. This worsened as the elevation to be measured increased. The cross-staff was mostly used to measure altitudes of less than fifty degrees. Otherwise, the astrolabe was preferred.[80] In addition, if the staff was not properly positioned right below the eye, errors were introduced to the measurement. When solar observations were made, the user had to stare at the sun. To solve this, some instruments had a tinted glass on one end of the crosspiece. Another problem was the material. Wood warps with changes in temperature and humidity, both common in a marine environment. This would have its effect on the instrument's accuracy. Nevertheless, the cross-staff remained popular among ship pilots until the nineteenth century.[81]

The Rincón Astrolabe

The instrument found at the wreck site in Rincón (NMM 63) is a typical cast-wheel astrolabe from the first half of the seventeenth century (**Fig. 11**).[82] From an archaeological standpoint, its most significant feature is an inscription that reads '1616' between two four-pointed stars on the front side of the bottom ballast, indicating the year of manufacture. At first glance, this could be considered the *terminus post quem* for the wreck. However, other artifacts found at the site suggest that the ship likely sank during the second half of the seventeenth century.

Sea astrolabes seldom allow the archaeologist to determine the nationality of a wrecked ship. This is due to the fact that, during the sixteenth and seventeenth centuries, most astrolabes were made either in Portugal or Spain. Although it is likely that the pertinent authorities in these countries prevented navigation instruments from winding up in the hands of pilots of other seafaring nations, avoiding such an exchange would have been virtually impossible. Other countries producing astrolabes at the time were The Netherlands, England and France. Iberian astrolabes were nonetheless predominant, and it can be proposed with certain confidence that the astrolabe found in Rincón is Spanish.

The first feature supporting an Iberian origin is the instrument's dimensions. It is 170 mm in diameter and 17 mm thick. According to Stimson, "Spanish and Portuguese astrolabe development in the seventeenth century appears to have stagnated after the instrument had stabilised at a diameter of about 180 mm and a thickness of about 20 mm."[83] Contemporary Iberian astrolabes such as the *Atocha* II (NMM 58) and *Atocha* IV (NMM 60), which were found in the wreck of *Nuestra Señora de Atocha*, a Spanish galleon that foundered in 1622, confirm this. The *Atocha* II, also manufactured in 1616, is 171 mm in diameter, 21 mm thick at the top and 22 mm at the bottom. For the *Atocha* IV, made in 1614, these dimensions are 172 mm, 20 mm and 21 mm, respectively. Both instruments are Portuguese.[84] On the *Atocha* II, a decorative four-pointed star appears on the outer ends of the spokes as they join the rim, a feature found on various Portuguese astrolabes. The *Atocha* IV has the inscription 'Y DIAS' on the front side of the bottom ballast. It has been theorized that this mark was used by Portuguese instrument maker João Dias.[85]

One difference between the Rincón astrolabe and its Portuguese counterparts is the scale, which is intended for measuring altitude instead of angular distance from the zenith. The latter is a Portuguese characteristic. The scale is graded in one-degree divisions, with multiples of ten on the inner side of the rim marking the degrees from zero on the horizontal, to ninety on the crown, and back to zero. On both sides, the zero-degree position is marked by a 'I.' The five-degree multiples are indicated by a '5' stamped between each pair of ten-degree divisions, but further outside along the rim's radius. All these features are contained within four pairs of circles that divide the rim in three sections.

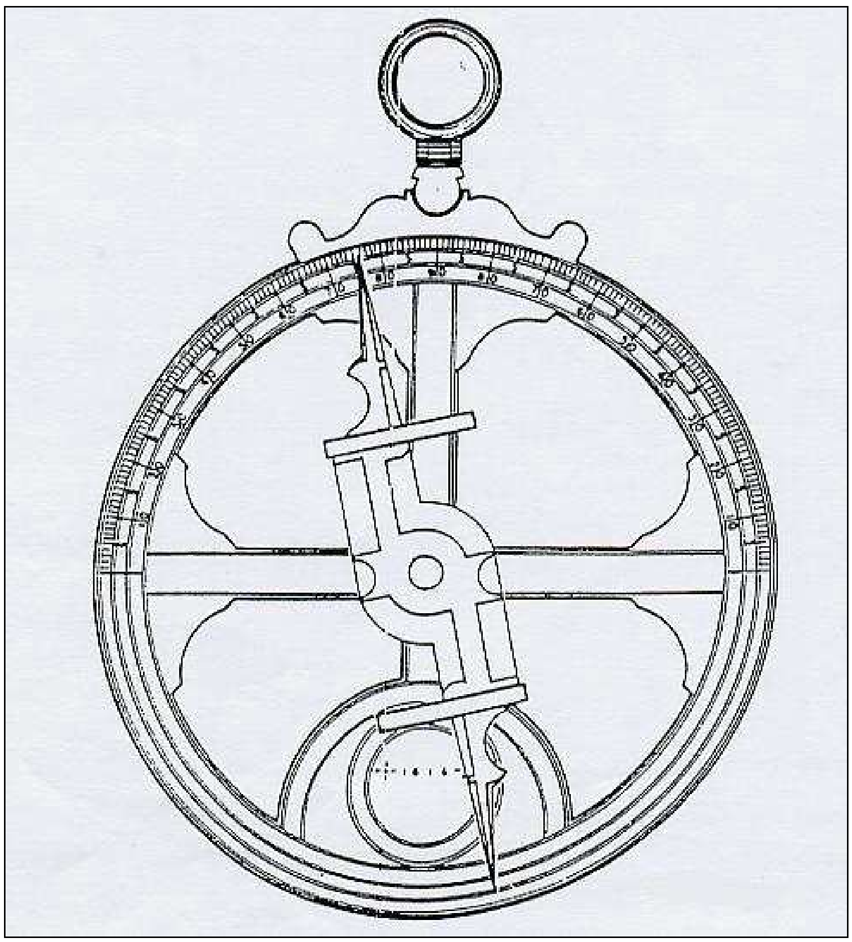

Fig. 11. The Rincón astrolabe. (Drawing by Angel L. Tirado of the Institute of Puerto Rican Culture)

The alidade, which is 165 mm long, was fixed on the 76-degree position when the astrolabe was found. The sighting vanes have a single pair of small orifices that are bigger on their outer face, indicating that the instrument was used to make solar observations. The distance between these vanes is 69 mm. The alidade is attached to the wheel's hub by a bolt with a threaded wing nut. This method was adopted by the turn of the sixteenth century and replaced the use of an axis pin with a wedge. The latter, a mechanism used in planispheric astrolabes, was also utilized by the early makers of nautical astrolabes.[86] The four spokes are also typical of contemporary Iberian manufacture. The lower one takes a semicircular shape as it joins the rim, while the remaining three acquire a bell-like shape at that location.

If we analyze the drawing of the wreck site presented in the previous section, it may be deduced that the astrolabe was found towards the stern of the ship. The fact that the instrument was buried under a thick layer of sand suggests that its context remained undisturbed. Astrolabes were usually stored in a chest, where the ship's pilot kept all the tools of his trade. Therefore, it is possible that there still remain other navigation instruments at the site. However, the presence of a wood chest has never been suggested by any of the salvors. An archaeological excavation at the site would allow us to shed light onto this matter. In the case additional instruments were found, they would help us to understand better the culture of navigation during the seventeenth century.

THE ARCHAEOLOGY OF THE SEA OR MARINER'S ASTROLABE

Given the vital role the mariner's astrolabe played in the process of European maritime expansion, it comes as a surprise that systematic studies on this instrument were not undertaken until the early twentieth century.[87] This may be due to the fact that most nautical astrolabes vanished after the early eighteenth century, when the instrument's popularity declined. During the late fifteenth and early sixteenth centuries sea astrolabes were sometimes made of wood. Wood is a perishable material and no wooden astrolabe from that period has been preserved. Astrolabes were also made of brass or bronze, which are both valuable metals. It is likely that, when devices that were more practical began to be used in navigation, most sea astrolabes were melted so their material could be reused.

In 1917, Portuguese mathematician Luciano Pereira da Silva authored the first two modern articles on the mariner's astrolabe. In one of them, he specifically presents the instrument now known as the Coimbra University astrolabe (NMM 18), then the only authentic astrolabe known to exist in Portugal.[88] Current knowledge, however, makes us doubt that this astrolabe was used at sea, given its diameter (508 mm) and weight (10,170 g). It is ironic that, as recently as ninety years ago, no sea astrolabe existed in the country where the instrument was first developed and used. It was only in 1926 that an article appeared on what is now undoubtedly known to be a nautical astrolabe. Once more, the author was Pereira da Silva and he was writing about an instrument recovered in 1903 at the port of Vera Cruz, Mexico, during dredging operations.[89] Seven years later, a work entitled *A Marinharia dos Descobrimentos* was published in Portugal. It dealt with all aspects of the Portuguese Age of Discovery. The author was Fontoura da Costa.[90] Among its content was a reference to the Portuguese *nao Madre de Deus*, which foundered in Nagasaki Bay, Japan, in 1610. The text indicates that, in 1928, an astrolabe was recovered at the site.

One may infer, from what we have discussed, that up until the mid-twentieth century research on the mariner's astrolabe was scant. This began to change in 1957, when Lieutenant Commander David W. Waters, officer of the English Royal Navy and Head of the Department of Navigation and Astronomy at the National Maritime Museum in Greenwich, published in the journal of *The Institute of Navigation* an article entitled "*A Tenth Mariner's Astrolabe*." As the title suggests, the text presented the ten nautical astrolabes that were known at the time.

After the 1960s, the self-contained underwater breathing apparatus (SCUBA), or Aqualung, was indirectly responsible for increasing the number of existing mariner's astrolabes. This new mechanism allowed people to remain underwater for relatively long periods with little movement constraints and the exploration of shipwrecks suddenly became the pastime of many. As a result, by 1966, only nine years after Water's first publication, the number of known nautical astrolabes had risen from ten to twenty-one. By 1988 the number skyrocketed to sixty-five. This does not mean that all instruments found after 1957 were recovered during underwater salvage or archaeological operations. However, most of them were. Of the forty-four astrolabes found between 1966 and 1988, thirty-three were recovered through SCUBA diving.

The first comprehensive work on the mariner's astrolabe was published by the *Junta de Investigações do Ultramar* of the *Universidade de Coimbra*, Portugal, in 1966.[91] The author again was Waters. This thirty-nine-page paper begins with a dedication to Pereira da Silva, recognizing him as the first modern scholar to study the nautical astrolabe. Following, the author presents the history of the instrument and its development through the sixteenth and seventeenth centuries, based mostly on literature and iconography from the period. The work concludes with notes on the twenty-one astrolabes known at the time, including measurements and features. The last page contains a scaled illustration of each artifact. In his work, Waters proposed a typology for sea astrolabes that has remained the standard:

Type I (a)	–	Wheel type with base ballast
Type I (b)	–	Wheel type with crown ballast
Type II (a)	–	Semi-sphere with base ballast
Type II (b)	–	Semi-sphere with crown ballast
Type III	–	Wheel type without ballast

Waters' work remained unparalleled until 1988, when Professor Alan Stimson published the book *The Mariner's Astrolabe: a Survey of Known, Surviving Sea Astrolabes*.[92] At the time, Stimson was Curator of Astronomy and Navigation at the National Maritime Museum in Greenwich. On July 1983, he presented a paper at the *IV Reunião da História da Náutica e da Hidrografia*, held in Lagos and Sagres, Portugal, which "was the spur to review the additional evidence provided by the forty-eight surviving astrolabes known at that time."[93] Stimson's work is similar in structure to that of Waters, although more extensive. It also begins with a historical introduction, but incorporates information that came to light after 1966. Most remarkably, it presents the information contained in Alexander Zorzi's manuscript of 1517, which features the earliest known illustration of a cast-wheel type astrolabe. Another innovation in Stimson's book is a discussion on copied and fake astrolabes. The typology proposed by Waters is extended by Stimson to include two new types. These are:

Type IV	-	Planisphere for marine use
Type V	-	Concentric ring type

Stimson's work presents the sixty-five nautical astrolabes known in 1988, including the twenty-one discussed in Water's paper. There is an illustration of each instrument, as well as their number and name, as Stimson and the National Maritime Museum registered them.[94] For each astrolabe, an initial list is given indicating its typology, date of manufacture, scales of limb, diameter, thickness, weight, nationality, marks and current location. Each entry also includes a description of the artifact, where the author discusses its theorized or known origin, its most remarkable features, similarities with other instruments and any other relevant information. At the end of his book, Stimson presents a bibliography and various appendices, most of which are tables highlighting the astrolabes' most significant characteristics. As in Waters' paper, a plate presenting scaled drawings of all the instruments is included. Stimson's work remains to this day the most authoritative source on nautical astrolabes.

THE ASTROLABES

It has been seventeen years since the publication of Stimson's book. As noted by the author in 1988, his survey would soon require upgrading, given the rate at which sea astrolabes were being recovered all over the world. This document presents those instruments that have been discovered since 1988. The list is not exhaustive and two artifacts did not yield much information. They are the Zacharchak (NMM 66), dated 1593 and found in the late 1980s near the coast of Cuba,[95] and the Ile de Brehat (NMM 85), from northern Brittany. Since SCUBA diving is an activity accessible to many, it is likely that numerous nautical astrolabes have been recovered that have yet to be registered.

Inés de Soto[96]

The Archipelago of Los Colorados is a reef barrier that runs for over a hundred miles parallel to the northern coast of Pinar del Rio, the westernmost province of Cuba. In May 1992, two divers from the Cuban underwater archaeology institution Carisub, S.A. were surveying an area two miles north of cay Inés de Soto, one of the islets that form the archipelago, when they came across a pile of concreted ballast. Further exploration revealed the presence of ordnance on the site. It was thus determined that the remains of a wrecked ship lay in the area. Between 1992 and 1995, a team from Carisub excavated the site, recovering a plethora of artifacts.

The guns found at the site allowed the team to date the wreck to sometime within the sixteenth century. Later, careful analysis of other artifacts suggested that the vessel foundered sometime between 1555 and 1566. Among the finds were silver and gold bullion, ceramics, over seventeen thousand coins, jewelry and other personal objects, ordnance, galley ware, two anchors and two astrolabes, which the Carisub staff recorded as PE-1 and PE-2.

Of the two astrolabes, PE-1 is the best preserved, despite that the entire upper right and some of the lower right quadrants are missing (**Fig. 12**). Around thirty-six percent of the instrument eroded during the centuries it spent on the seabed. The portion that remains weighs 1,380 grams, so it is estimated that the artifact's original weight was 2,156 grams. It is 202 mm in diameter and 14 mm thick (**Table 1**). On the front side of its bottom ballast is the inscription '1555,' year in which the astrolabe was manufactured (**Fig. 13)**. This instrument is undoubtedly Spanish and very similar to the Palermo (1540, NMM 1) and the Arts et Métiers I (1563, NMM 24). The former is thought to be Portuguese, while the latter is Spanish. The three specimens are within 4 mm in diameter and 1 mm in thickness.

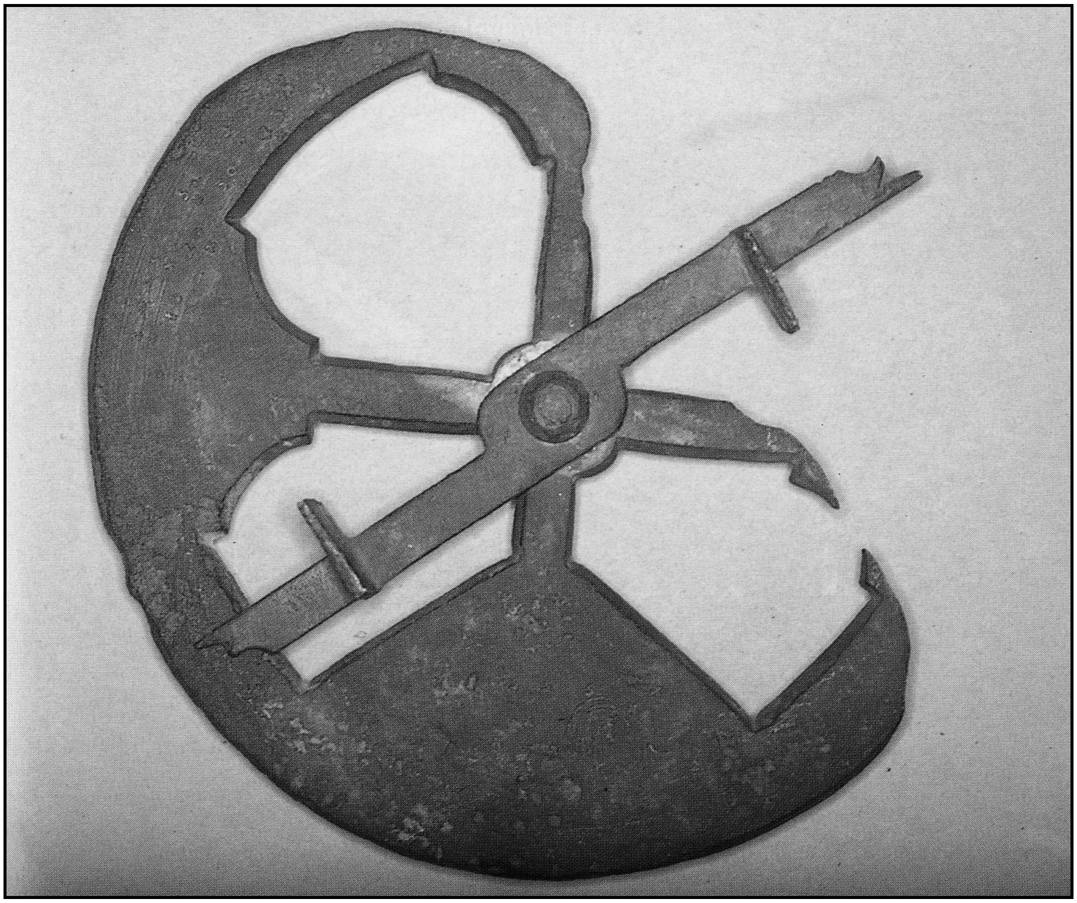

Fig. 12. The PE-1 astrolabe. (After Dulcila Cañizares' *Naufragio en Inés de Soto: un hallazgo de cuatro siglos*)

The PE-1 astrolabe is graded to measure altitude, a typical Spanish feature. A stamp of the Pillars of Hercules is partially discernable on the lower right corner of the date inscription. This mark confirms that the instrument was examined and approved by the *Piloto Mayor* of the *Casa de Contratación*, the Spanish institution that oversaw all aspects of the Crown's overseas affairs. The bottom ballast is triangularly shaped, a typical feature of mid-sixteenth century astrolabes. The alidade, partially eroded, still has its two sighting vanes. They are 101.5 mm apart and are pierced by holes that are larger on their outer side. This suggests that the alidade was used to make solar observations. The instrument's suspension ring is absent.

Table 1. The PE-1 astrolabe (data and statistics)

Type	Ia
Date	1555
Scales of Limb	0-90-0
Diameter	202 mm
Top Thickness	14 mm
Bottom Thickness	14 mm
Actual Weight	1,380 g
Estimated Original Weight	2,156 g
Nationality	Spanish
Marks	Various (see description)
Location	Havana, Cuba

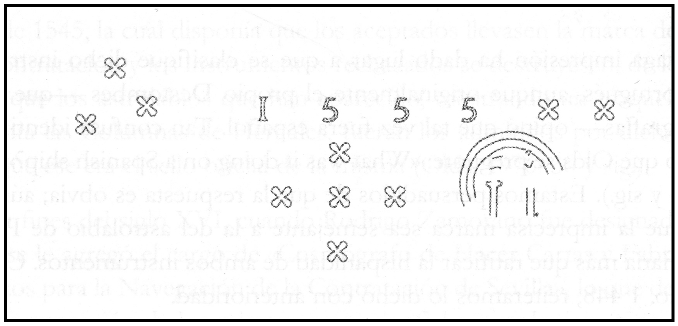

Fig. 13. Inscriptions on the PE-1 astrolabe, including the date of manufacture and the Pillars of Hercules. (after Dulcila Cañizares' *Naufragio en Inés de Soto: un hallazgo de cuatro siglos*)

The most remarkable feature of this astrolabe is its marks, which are unique in the archaeological record. At the point where the left spoke joins the rim, five 'x's were stamped forming a cross. This pattern also appears below the '1555' inscription. To the left and right sides of the '1555,' three 'x's and two 'x's were stamped respectively. Additionally, two circles of 'x's are inscribed around the astrolabe's perimeter. The one on the inner rim marks the ten-degree divisions along the circumference. The other, which lies halfway between the inner and outer edges, marks the five-degree divisions (**Fig. 14**). As of 1998, the PE-1 astrolabe was kept in the facilities of Carisub, S.A. in Havana.

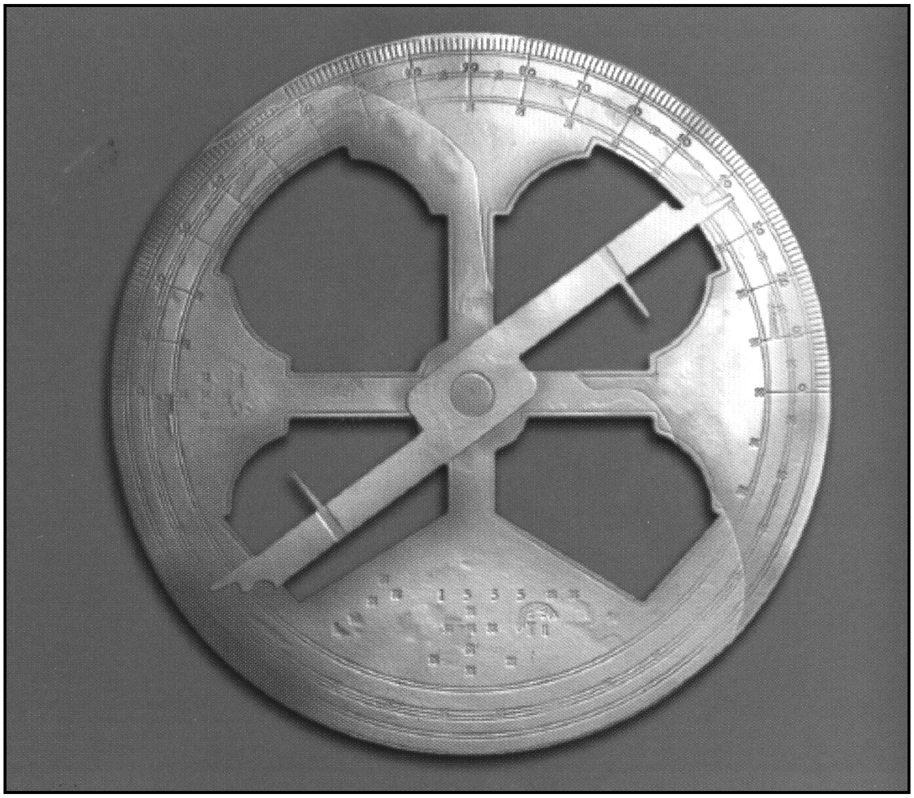

Fig. 14. Reconstruction of the PE-1 astrolabe showing all its marks. (After Dulcila Cañizares' *Naufragio en Inés de Soto: un hallazgo de cuatro siglos*)

PE-2 is a type Ia astrolabe, although its poor state of preservation makes it difficult to perform a useful analysis (**Fig. 15**). It is likely that this artifact was also manufactured around the mid-sixteenth century. It is 170 mm in diameter. Currently, it weighs 339 g and is 10 mm thick (**Table 2**). However, these statistics are relatively useless given the instrument's condition. Both the suspension ring and the alidade are missing and neither marks nor a scale may be discerned. A loose alidade was found at the site, but its dimensions suggest that it did not belong to PE-2. It is thus likely that another astrolabe was carried in the wrecked ship. After its recovery, PE-2 was stored with its counterpart in Havana.

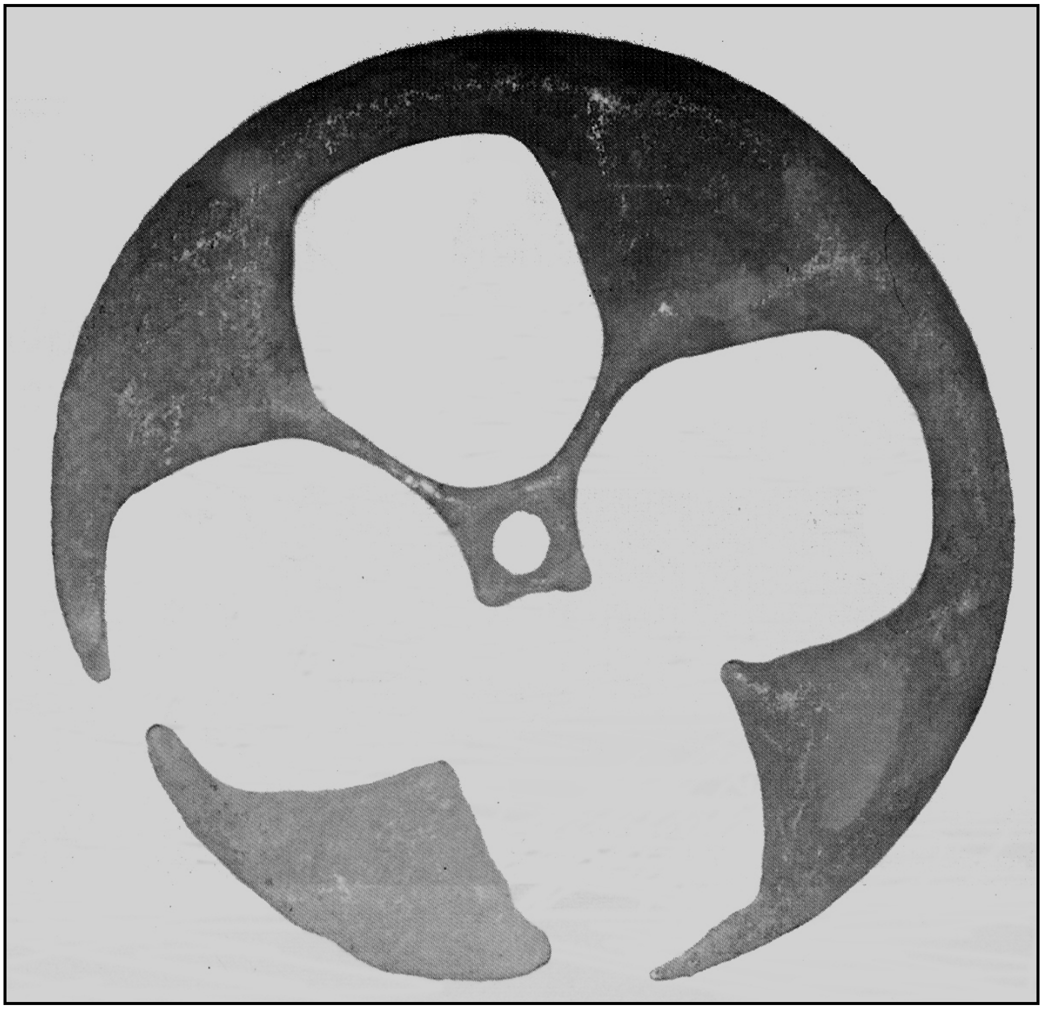

Fig. 15. The PE-2 astrolabe. (After Dulcila Cañizares' *Naufragio en Inés de Soto: un hallazgo de cuatro siglos*)

Table 2. The PE-2 astrolabe (data and statistics)

Type	Ia
Date	*c*. 1550
Scales of Limb	None discernable
Diameter	170 mm
Top Thickness	10 mm
Bottom Thickness	10 mm
Current Weight	339 g
Nationality	Spanish?
Marks	None discernable
Location	Havana, Cuba

Aveiro

This astrolabe, which is in an excellent state of preservation, was found in an unidentified wreck in Ria de Aveiro, Portugal, in 1994 (**Fig. 16**). It is a typical example of Iberian manufacture from the second half of the sixteenth century, similar in shape and features to four others: the Tenri (ante 1609, NMM 10), *Girona* II (ante 1588, NMM 27), *Atocha* I (*c*. 1600, NMM 34) and Mounts Bay (1550-1600, NMM 46) astrolabes.

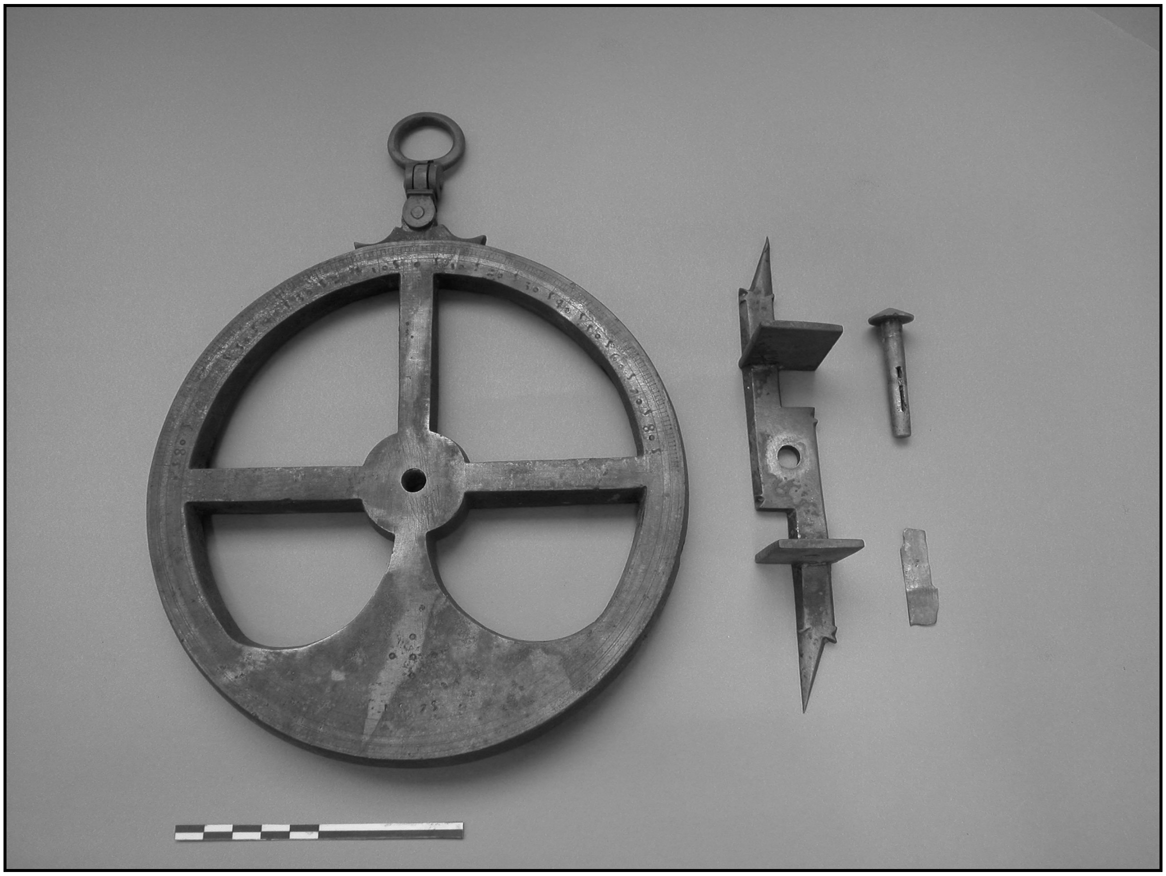

Fig. 16. The Aveiro astrolabe with all of its components. (Photo courtesy of the *Centro Nacional de Arqueología Náutica e Subacuática*, Lisbon)

As with its four counterparts, the Aveiro astrolabe has a wedge-shaped section, although much less pronounced (**Table 3**). The bottom ballast resembles a bell rather than a semicircle, a characteristic shared by these five instruments. The five circles forming a cross on the front side of the ballast attest to its Portuguese origin, as does the scale, which is graded for zenith distance. The figure '90' was not stamped on the rim. The manufacture date, 1575, can be clearly seen below the five-circle mark. Both the alidade and the suspension ring are in good condition. The alidade is secured to the hub by an axis pin with a wedge driven through a slot, a feature replaced in the late sixteenth century by the threaded bolt with a wing nut. The lateral and upper spokes are of constant width. The projection on which the suspension ring rests serves as an ornament and is found, with identical shape, on various astrolabes dated within this period.

Table 3. The Aveiro astrolabe (data and statistics)

Type	Ia
Date	1575
Scales of Limb	90-0-90
Diameter	197 mm
Top Thickness	15 mm
Bottom Thickness	19 mm
Weight	2,770 g
Nationality	Portuguese
Marks	‘1575’ and five circles forming a cross
Location	*Museu de Marinha*, Lisbon, Portugal

Museo Naval

The *Museo Naval* in Madrid acquired this astrolabe from Sotheby’s in 2001. Nothing else is known about its origin. However, metallurgical analyses suggest the instrument was manufactured in Spain during the sixteenth century.[97] It is made of bronze and is excellently preserved (**Fig. 17**)

Fig. 17. The astrolabe at the *Museo Naval*. (Photo courtesy of the *Museo Naval*, Madrid)

Arguably, the most remarkable feature is its four spokes, which are elaborately shaped at the points where they join the rim. The bottom ballast of the *Museo Naval* astrolabe is similar to that of the Red Bay (NMM 55). Remarkably, both instruments share identical dimensions (**Table 4**). The Red Bay astrolabe was recovered from a Spanish shipwreck in Labrador, Canada, in 1984. During the sixteenth century, Red Bay was an important outpost of the Basque whaling industry. It is, therefore, reasonable to ascribe a Spanish origin to both instruments. The Red Bay astrolabe has been dated to between 1525 and 1575, and the artifact from the *Museo Naval* may also be placed within this timeframe.

The scale of the *Museo Naval* astrolabe is graded for measuring altitude, another indication that the instrument is likely Spanish. There are no numbers stamped at the zero-degree position. The five-degree marks, located between the multiples of ten degrees, show eight-pointed stars instead of digits. Three such stars also appear at the top of the rim, on the projection supporting the suspension ring, arranged as the vertices of an inverted triangle (**Fig. 18)**. Two other eight-pointed stars are stamped on the ornamental lobes on each side of the suspension ring.

The alidade of the *Museo Naval* astrolabe is missing, although its suspension ring is intact. The instrument's remarkable condition makes it likely that the alidade was removed rather than worn away. This is, however, impossible to ascertain, given the artifact's obscure origin.

Table 4. The astrolabe at the *Museo Naval* (data and statistics)

Type	Ia
Date	Mid 16th century
Scales of Limb	0-90-0
Diameter	205 mm
Top Thickness	15 mm
Bottom Thickness	15 mm
Weight	Not available
Nationality	Spanish?
Marks	Various eight pointed stars (see text)
Location	*Museo Naval*, Madrid, Spain

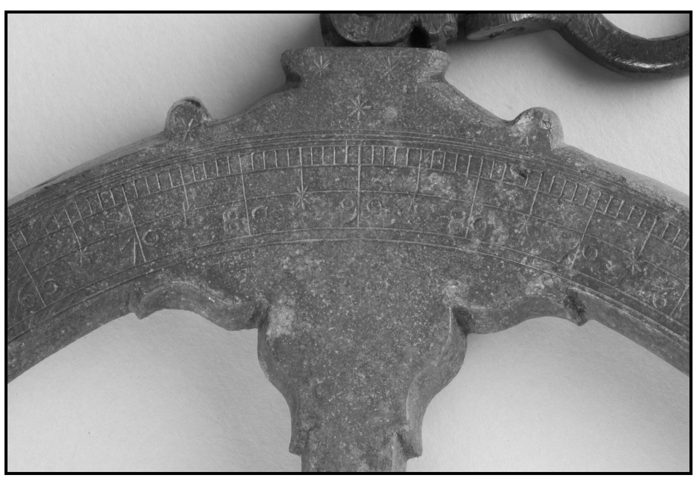

Fig. 18. Eight-pointed stars on the *Museo Naval* astrolabe. (Photo courtesy of the *Museo Naval*, Madrid)

Francisco Padre [98]

This astrolabe was presented as a gift to a member of Spain's royal family by the French underwater explorer Franck Goddio. It was supposedly found on a wreck site near Cape San Antonio, off Cuba's northwestern coast, in an area known as Francisco Padre. Given its obscure origin, it is difficult to ascertain the instrument's authenticity (**Fig. 19**).

Fig. 19. The Francisco Padre astrolabe. (Photo courtesy of the *Museo Naval*, Madrid)

This artifact is fairly well preserved. It is similar in shape to five other instruments: the Tenri (NMM 10), *Girona* II (NMM 27), *Atocha* I (NMM 34), Mounts Bay (NMM

46) and Aveiro astrolabes. Among these, four have been positively identified as Portuguese and all have been dated to the second half of the sixteenth century. The scale, graded for zenith distance, indicates that, if authentic, this instrument was also manufactured in Portugal. The diameter is the same as that of the *Atocha* I and only 1 mm less than the Tenri astrolabe. As with all its counterparts, the Francisco Padre has a wedge-shaped section (**Table 5**).

The alidade is held in place by a modern bolt (**Fig. 20**). The suspension ring is absent. Strangely, given the state of preservation, no trace of ornament remains on the crown. At the time this work was written, the Francisco Padre astrolabe was stored at the *Museo Naval* in Madrid, Spain.

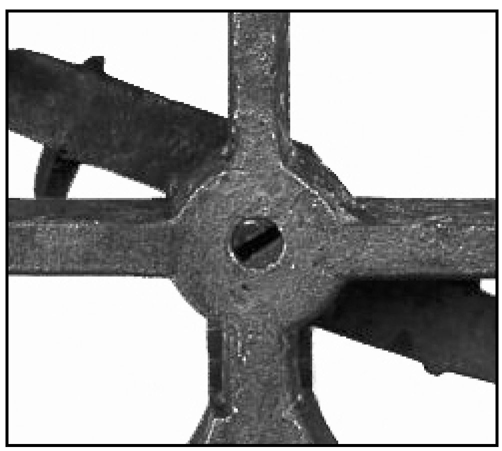

Fig. 20. Bolt holding the alidade of the Francisco Padre astrolabe. (Photo courtesy of the *Museo Naval*, Madrid)

Table 5. The Francisco Padre astrolabe (data and statistics)

Type	Ia
Date	c. 1550-1600
Scales of Limb	90-0-90
Diameter	185 mm
Top Thickness	19 mm
Bottom Thickness	25 mm
Weight	Unavailable
Nationality	Portuguese
Marks	None discernable
Location	*Museo Naval*, Madrid, Spain

San Diego

The Manila galleon *San Diego* sank on 14 December 1600, twenty miles south of Manila Bay, while fighting *Mauritus*, a Dutch ship whose crew was largely outnumbered by the Spaniards. In 1598, the Dutch government sent five fleets to the East Indies, hoping to learn the routes the Spanish and the Portuguese followed in their trade with the Far East. Three sailed eastward, while two sailed to the west. *Mauritus*, captained by Olivier van Noort, sailed with the second fleet that left The Netherlands westbound. After enduring the harshness of global circumnavigation, they arrived in the Philippines on 16 October

1600. There, the only two remaining ships, *Mauritus* and *Eendracht*, managed to get food and water from the Spaniards. Gathering information, the Dutch learned of the extensive commercial activity in the area. They figured that, if they lingered, they could get prize through piracy. Knowing that the fleet bringing silver from Acapulco was due to arrive on December, the Dutch headed to Manila Bay.

When the Spanish found out that the Dutch were bound to Manila they panicked. The island's defensive fleet was away at the time fighting Muslims to the south. Without any warships available, the Spaniards were forced to outfit two merchantmen to repel the invaders. The vessels chosen for the task were *San Diego*, captained by Antonio de Morga, and *San Bartolomé*, captained by Juan de Arcega. Morga had no previous military experience. According to witnesses interviewed after the battle, this was the main cause of *San Diego's* demise.

With 450 men (and perhaps some women) onboard, *San Diego* went into battle so heavily loaded that the lower gunports were underwater. With a full hold, there was no space in the ship to handle the cannon. As the Spanish approached the Dutch, the latter prepared for engagement. *Mauritus* fired the first shot, damaging the mainsail and one of the pumps of *San Diego*. When one officer told Morga that the cannon could not be fired because there was no space and that the ship was taking water through the gunports, he ordered to grapple *Mauritus*. *San Diego* rammed *Mauritus* at full speed, suffering extensive hull damage. Then a group of Spaniards boarded *Mauritus*. Largely outnumbered, the Dutch went into the holds. Finding no resistance, the Spanish declared victory. Apparently seasick, Morga stayed in *San Diego* unable to command his men. When *Mauritus* was supposedly captured, *San Bartolomé* went after *Eendracht*.

Suddenly, a small fire broke out inside *Mauritus*, started by van Noort in an attempt to get his men out of the hold. By this time, the Dutch had noticed that Morga was unable to control the situation. Gaining courage, *Mauritus*' crew went on deck firing against the Spaniards. In the ensuing havoc, Morga ordered his men to cut the ropes joining the two ships and to board *Mauritus*. It was, nevertheless, too late for *San Diego*, which had at that point taken too much water. As soon as the two vessels became disentangled, *San Diego* went straight to the bottom with most of its crew. Three hundred fifty men perished on the Spanish side. Among the Dutch, five died and twenty-six were wounded.

San Diego was located in 1991 by a team led by French underwater explorer Franck Goddio. Based on Morga's account that he swam from the battle site to Fortune Island, Goddio defined a survey area 2.25 miles long by 1.5 miles wide. With the aid of three nuclear magnetic resonance magnetometers, the team found the wreck site at a depth of 170 feet, a quarter of a mile from the shore.

Two field seasons were held in 1992 and 1993, during which the site was excavated and the hull remains partially recorded. The site yielded an enormous amount of artifacts that reflect the cosmopolitan nature of *San Diego's* crew. Among the finds were weapons, jars, Mexican tableware, jewels, devotional objects, Chinese tableware, coins, personal objects and two navigation instruments: an astronomical circle and a mariner's astrolabe.

The *San Diego* astrolabe is made of bronze and is in a fair state of preservation. It is 183 mm in diameter, 17 mm thick at the top and 18 mm at the bottom (**Table 6**). This could suggest a wedge-shaped section. However, such a small difference could also be explained as an imprecision in manufacture. The lateral and top spokes maintain a constant width as they join the instrument's rim, while the bottom spoke turns into a semicircle that serves as ballast. The two upper quadrants are graded at five-degree intervals with tick marks. However, there are no digits stamped on the scale. This curious feature repeats itself on the Greenwich (*Valencia*) astrolabe (NMM 4). In 1988, Stimson theorized that this could be an exception by the manufacturer, given a possible rush in the instrument's fabrication. Nevertheless, the recurrence of this characteristic in the *San Diego* astrolabe suggests this may have been the practice of a particular maker (**Fig. 21**).

The alidade of the *San Diego* was cast as a single metal piece. The sighting vanes were pierced for solar observations, with holes that are larger on the outer face. The axis pin is secured by a wedge rather than a wing nut, a practice abandoned by the end of the sixteenth century.[99]

Table 6. The *San Diego* astrolabe (data and statistics)

Type	Ia
Date	1575 - 1600
Scales of Limb	Degrees marked, but unnumbered
Diameter	183 mm
Top Thickness	17 mm
Bottom Thickness	18 mm
Weight	2,434 g
Nationality	Portuguese?
Marks	None discernable
Location	National Museum of the Filipino People, Manila, Philippines

The suspension ring of the *San Diego* astrolabe is mounted on a mechanism that allows it to swing both laterally and perpendicular to its main plane. It has two peculiar protrusions, one on each side, which allow the instrument to be suspended by three fingers. This feature is also found in the *Kronborg* (1600, NMM 5), *Barlow* (1602, NMM 7), *Caudebec* (1632, NMM 17) and *Banda* I (1568, NMM 43) astrolabes. Although no date or marks are present, based on its provenience and the characteristics it shares with the aforementioned artifacts, this astrolabe is most likely Iberian and was manufactured around the last quarter of the sixteenth century.

Fig. 21. The *San Diego* astrolabe. (After J.P. Desroches' *Treasures of the San Diego*)

São Julião da Barra

On the night of 14 September 1606, the Portuguese *nau Nossa Senhora dos Mártires* ran aground in front of fort *São Julião da Barra* at the mouth of the Tagus River, Lisbon, Portugal. The vessel was homeward bound from Cochin, India, after a year-and-a-half roundtrip to the Indian subcontinent. The journey, known as the *Carreira da India*, was undertaken yearly by many Portuguese ships as part of the commercial scheme established by the Crown after Vasco da Gama opened the maritime route to Asia in 1498. The ship sank swiftly with all the cargo in its hold. During the following days, both royal authorities and civilians recovered whatever they could. It is likely that, years later, agents of King Phillip II of Portugal made further efforts to salvage valuable objects (cables, anchors and guns) from the shallow wreck site. However, as with many ships that sank in the *Carreira*, *Nossa Senhora dos Mártires* soon vanished from memory.

In 1993 Francisco Alves, then Director of the Portuguese *Museu Nacional de Arqueologia*, directed a survey in front of fort *São Julião da Barra* and identified two zones with archaeological potential. They were designated *São Julião da Barra* 1 (SJB1) and *São Julião da Barra* 2 (SJB2). The first encompassed a large area littered with iron guns, while the second consisted of the remains of a wooden hull with shards of Ming porcelain and Chinese earthenware dating from the late sixteenth or early seventeenth century. Archival research suggested the hull was that of *Nossa Senhora dos Mártires*.

In 1996 and 1997, under the direction of Alves assisted by Filipe Castro, excavations were conducted on site SJB2. Numerous artifacts were recovered, including two pairs of navigational dividers, various sounding leads, porcelain, stoneware, earthenware and objects made of brass, copper, pewter and silver. Also among the finds, and most important to this study, were three nautical astrolabes.

None of the astrolabes found at SJB2 can be positively related to the crew of *Nossa Senhora dos Mártires*, due to the process of archaeological formation at the site. Not only has this area been repeatedly exposed to strong currents and surges, but many ships have wrecked on the sandbars near fort *São Julião da Barra* throughout the centuries. This often makes it impossible to ascertain which artifacts belong to which shipwrecks. Furthermore, the 1755 earthquake that destroyed Lisbon created a tidal wave that most likely caused great disturbance in the area. However, since the three astrolabes are likely to have been manufactured within a relatively short time span, they have all been associated to the wrecked *Nossa Senhora dos Mártires*. Two of the SJB astrolabes (SJBII and SJBIII) were found, together with two nautical dividers, in an area where archaeologists believe the port side of the stern castle may have rested.[100]

Four centuries of abrasion took their toll on the SJBI astrolabe (NMM 78), which is in a poor state of preservation (**Table 7**). This instrument is made of brass, but the metal also contains high concentrations of lead and tin. Although the suspension ring is missing, its holding shaft is still in place. Only a portion of the alidade survives. Both sighting vanes are absent. The bottom ballast is shaped in a semi-circle (**Fig. 22)**.

Three rivets were placed on the front face of this astrolabe by its manufacturer, at seemingly random locations. It has been theorized that these were meant to fill voids left on the instrument's surface during the casting process. The scale is completely obliterated and there are no discernable marks. Little more can be said about this artifact besides the fact that, at least aesthetically, its date of manufacture can be placed somewhere between *c*. 1575 and *c*. 1625.[101]

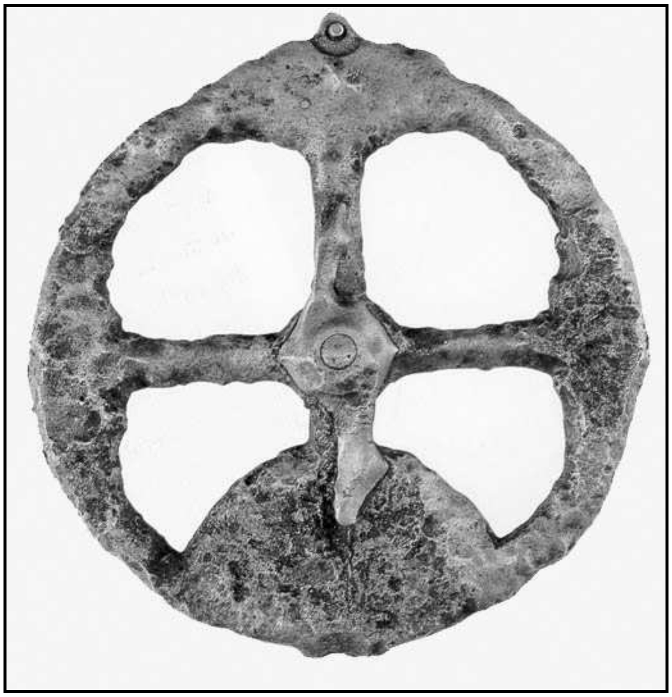

Fig. 22. The SJBI astrolabe. (Photo courtesy of Filipe Castro)

As its counterpart, SJBII (NMM 79) was severely eroded during the centuries spent on the bottom of the Tagus River. The suspension ring is missing. A small portion of the alidade survives, in the area where it joins the wheel's hub. Conservation work revealed a small section of the scale. Since the instrument was graded for zenith distance, it can be confirmed to be Portuguese (**Table 8**).

Table 7. The SJBI astrolabe (data and statistics)

Type	Ia
Date	*c*. 1575 – *c*. 1625
Scales of Limb	Obliterated
Diameter	167 mm
Top Thickness	16 mm
Bottom Thickness	18 mm
Weight	1,690 g
Nationality	Iberian
Marks	None discernable
Location	*Museu de Marinha*, Lisbon, Portugal

Somewhat peculiar to this astrolabe are the five-degree marks, which are at the same radial distance from the hub as the ten-degree marks, rather than further outside, as is usually the case in similar instruments. This can only be found in the Dundee (1555, NMM 2), Aveiro (1575) and *Atocha* I (*c*. 1600, NMM 34) astrolabes, all of which are Portuguese.[102]

Table 8. The SJBII astrolabe (data and statistics)

Type	Ia
Date	*c*. 1575 – *c*. 1625
Scales of Limb	90-0-90
Diameter	173 - 175 mm
Top Thickness	22 mm
Bottom Thickness	20 mm
Weight	1,769 g
Nationality	Portuguese
Marks	None discernable
Location	*Museu de Marinha*, Lisbon, Portugal

The bottom ballast of this artifact is shaped in a semicircle. The upper and longitudinal spokes widen as they join the rim in a shape resembling a bell. This design is identical to that of nineteen other astrolabes manufactured between 1540 and 1650, of which sixteen are Portuguese.[103]

A curious detail about this instrument is that its rim is fractured at the right lower quadrant. It has been suggested that, as the casting mold was being filled with molten brass, the metal reached the point of the fissure at different temperatures. Even though at that spot the metal would have partially fused, this created a structurally weak section.

Although it is unlikely that the instrument was broken in use, the abrasion it endured during the centuries may have exposed this construction flaw. Albeit a precise manufacture date cannot be determined, it is likely that this instrument was built during the last quarter of the sixteenth century, or in the early seventeenth century (**Fig. 23**).

Fig. 23. The SJBII astrolabe. (After A. Estácio dos Reis' ***Astrolábios náuticos em Portugal)***

SJBIII's (NMM 83) pristine condition makes it the best preserved astrolabe in the *São Julião da Barra* collection (**Fig. 24**). It was recovered from beneath a rock, which prevented the abrasive action of the surrounding elements. The fact that it rested under a heavy load makes it the least likely to be intrusive. Therefore, this is the instrument we may relate to the *Nossa Senhora dos Mártires* most confidently. This artifact, which is made of brass, was found in close association with an iron cannon. Through the centuries, the cannon released a flow of electrons that helped to create a protective layer that prevented chemical decomposition.[104]

Fig. 24. The SJBIII astrolabe. (Photo courtesy of Filipe Castro)

The origin of this astrolabe is clearly Portuguese, given its scale, graded on the two upper quadrants for zenith distance (**Table 9**). A ‘I’ is incised in the zero-degree position, a characteristic shared by ten other astrolabes, both Spanish and Portuguese.

At the wheel's bottom, beneath the ballast, a letter 'G' can be clearly distinguished. This mark is also found, in the same location, on the *Atocha* III astrolabe (NMM 59), with which the SJBIII shares other similarities. These are the date of manufacture, a constant width in the lateral and upper spokes as they join the rim, scale format and alidade shape. The *Atocha* III is, nonetheless, 18 mm smaller and substantially lighter. Still, this does not preclude the possibility that both instruments were made by the same craftsman. Although it has been suggested that the letter 'G' is the maker's mark of Francisco de Goes, Stimson clearly states in his work that said symbol "might or might not indicate" a connection to the Goes, a Portuguese family of instrument makers active from around 1587 until the late seventeenth century.[105]

The bottom ballast of SJBIII is shaped in a semicircle. On it, the instrument's date of manufacture (1605) is clearly visible between four six-pointed stars (**Figure 25**). The alidade is in perfect condition, with its sighting vanes spaced at 65 mm and pierced for solar observations. It is attached to the wheel by a threaded pin and a wing nut. The suspension ring is mounted on a mechanism that allows the astrolabe to swing about both its lateral and perpendicular axes. Two lobes, one on each side of the suspension ring, serve as decoration.

Fig. 25. Bottom ballast of the SJBIII astrolabe, with the date of manufacture. (Photo courtesy of Filipe Castro)

Table 9. The SJBIII astrolabe (data and statistics)

Type	Ia
Date	1605
Scales of Limb	90-0-90 (I)
Diameter	174 mm
Top Thickness	20.3 mm
Bottom Thickness	21.4 mm
Weight	2,843 g
Nationality	Portuguese
Marks	‘G’ and the date of manufacture between four six-pointed stars
Location	*Museu de Marinha*, Lisbon, Portugal

Dry Tortugas Deep Water Shipwreck

Shrimp fishermen discovered this shipwreck in the late 1960s off the coast of Florida, near the Dry Tortugas islets. While dragging their deep-water nets, the men brought up artifacts from the bottom, including a Spanish olive jar from colonial times. Robert Marx was informed of the find and its approximate location, but a site depth of approximately four hundred meters made its excavation improbable at the time.

In 1988, a group of investors known as Seahawk Deep Ocean Technology joined Marx in an effort to relocate the wreck. With the advances made in deep water exploration technology during the previous twenty years, it was not hard to find the site. Between 1990 and 1991, a team from Seahawk began excavations, and by the late 1990s, thousands of artifacts had been recovered. This became the first underwater salvage operation in history that was entirely performed with the use of a Remotely Operated Vehicle (ROV).

It has been theorized that this vessel was sailing with the 1622 Spanish *Tierra Firme* fleet, of which the famous *Atocha* and *Santa Margarita* were part. However, no conclusive evidence of this has been presented. The vessel's cargo consisted mostly of earthenware, gold bullion and personal and religious effects. Three sea astrolabes were also found at the site, according to an interim archaeological report released by Seahawk in the summer of 1999. The three instruments are currently stored in a conservation facility in Sarasota, Florida. They belong to Odyssey Marine Exploration, an underwater exploration and recovery company founded in 1994 by the staff of the former Seahawk Deep Ocean Technology. The astrolabes were recorded as *Seahawk* I, II and III, presumably after the ROV with which they were recovered. A fourth specimen, purchased by Odyssey at auction, is also kept with the assemblage. These four comprise one of the largest collections of nautical astrolabes in the world, second only to that of the *Museu de Marinha* in Lisbon, Portugal.

Seahawk I is a type Ia Iberian astrolabe manufactured most likely during the first half of the seventeenth century (**Fig. 26**). A substantial portion of the alidade, 148 mm in length, is still held in place by what remains of the axis pin. Portions of the sighting vanes are also there, although they broke beneath the observation pinholes (**Fig. 27**). The suspension ring is missing. Neither a scale nor marks may be distinguished, since most of the original surface has eroded. Similar examples are the *Sacramento* A (NMM 38), *Sacramento* B (NMM 39), Isle aux Morts (NMM 44), *Santa Escolástica* (NMM 49), *Banda* II (NMM 56), Rincón (NMM 63) and Cádiz I (NMM 65) astrolabes. Nevertheless, *Seahawk* I is larger (from 11 to 19 mm in diameter and 3 to 7 mm in thickness) than its counterparts (**Table 10**). The fact that the *Seahawk* I has no discernible marks makes it impossible to draw any further parallels.

Fig. 26. The *Seahawk* I astrolabe. (Photo by the author)

Fig. 27. Broken sighting vanes on the *Seahawk* I astrolabe. (Photo by the author)

Table 10. The *Seahawk* I astrolabe (data and statistics)

Type	Ia
Date	*c*. 1600-50
Scales of Limb	Not discernable
Diameter	186 mm
Top Thickness	23 mm
Bottom Thickness	24 mm
Weight	Approximately 3,080 g[106]
Nationality	Iberian
Marks	None discernable
Location	Sarasota, Florida, USA

The *Seahawk* II (NMM 68) is the most remarkable astrolabe of the collection. The author was unable to inspect this artifact, as it was not at the conservation facility where it is usually stored in the spring of 2005. Consequently, data presented in this document comes from a preliminary report dated July 1999 and prepared by archaeologist Jenette Flow. One unusual feature of this instrument is the image of an armillary sphere stamped on the front side of the ballast (**Fig. 28**). Only one other astrolabe in the archaeological record shares this trait: the Zacharchak (NMM 66), dated 1593 and recovered during the late 1980s off the Cuban coast. The armillary sphere was the official symbol of the administration of Dom Manuel I, king of Portugal from 1495 to 1521. Hence, it is theorized that this mark may have been stamped on instruments coming from the *Armazéns Reais*, the Portuguese royal warehouses.[107] This suggests that both astrolabes share a Portuguese origin. However, it must be kept in mind that both instruments were manufactured long after King Manuel I died. In Spain, a mark showing the Pillars of Hercules was stamped on instruments inspected by the pertinent authorities. Perhaps the armillary sphere was the symbol used in Portugal for this purpose. However, this is purely speculative.

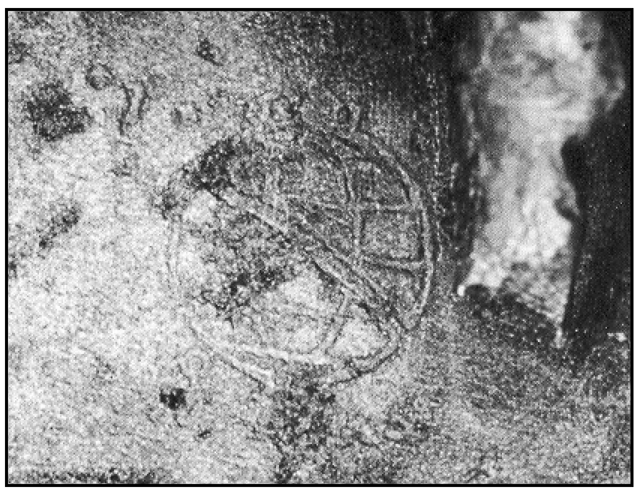

Fig. 28. Image of an armillary sphere stamped on the *Seahawk* II astrolabe. (After A. Estácio dos Reis' *Astrolábios náuticos em Portugal*)

The suspension ring of the *Seahawk* II is absent, but a portion of the alidade survives. The instrument is 171 mm in diameter, being more in accord with the typical Iberian astrolabe from this period. It is 26 mm thick and weighs 3,126 g (**Table 11**).

Table 11. The *Seahawk II* astrolabe (data and statistics)

Type	Ia
Date	*c*. 1600-50
Scales of Limb	Unknown to the author
Diameter	171 mm
Maximum Thickness	26 mm
Weight	3,126 g
Nationality	Portuguese?
Marks	Armillary sphere
Location	Sarasota, Florida, USA

The cast wheel of *Seahawk* III is fairly well preserved, but no part of the alidade survived. A portion of the axis pin remains. The suspension ring is also absent, but again, the pin is still there. Like its two counterparts, this astrolabe is a typical example of Iberian manufacture from the first half of the seventeenth century. As with *Seahawk* II, its diameter is close to that of most instruments within this typology (**Table 12**). Although most of the original surface is eroded, the upper spoke shows the pairs of thin lines typically present on similar specimens (**Fig. 29**).

Table 12. The *Seahawk* III astrolabe (data and statistics)

Type	Ia
Date	c. 1600-50
Scales of Limb	Not discernable
Diameter	173 mm
Top Thickness	21 mm
Bottom Thickness	23 mm
Weight	Approximately 2,540 g
Nationality	Iberian
Marks	None discernable
Location	Sarasota, Florida, USA

Fig. 29. The *Seahawk* III astrolabe. (Photo by the author)

A fourth astrolabe is kept with this assembly, although it was not found at the Dry Tortugas site. Odyssey Marine Exploration acquired this instrument at auction, but the author knows nothing else about its origin. The difference between this and the other three specimens is evident, as this is a typical Iberian astrolabe from the second half of the sixteenth century. In its shape and characteristics, it is similar to the Tenri (ante 1609, NMM 10), *Girona* II (ante 1588, NMM 27), *Atocha* I (*c*. 1600, NMM 34), Mounts Bay (1550-1600, NMM 46) and Aveiro (1575) astrolabes.

As its counterparts, this artifact has a conspicuous wedge-shaped section (**Table 13**). Although the wheel is fairly well preserved, all features on its surface are abraded, rendering it impossible to ascertain a specific nationality of manufacture, even though it is most likely Iberian. The suspension ring is absent, but its support remains. Pictures from the auction show that a small portion of the alidade survived. This, however, is no longer present. A portion of the axis pin remains. The lateral and upper spokes widen slightly as they join the rim, while the bottom spoke acquires a bell-like shape to form the ballast.

The dimensions, shape and certain features of this instrument are surprisingly similar to the Mounts Bay astrolabe, found in Cornwall, England, in 1982. Especially remarkable is a slight curvature to the left noticeable on the upper spoke of both instruments (**Fig. 30**). When describing the Mounts Bay astrolabe, Stimson asserts that a portion of the scale is vaguely discernable. This is not the case with this artifact. However, such resemblances suggest that we could be dealing with either the same instrument or one that was cast in the same mold.

Table 13. Data and statistics of the fourth astrolabe in the *Seahawk* collection

Type	Ia
Date	1550-1600
Scales of Limb	None discernable
Diameter	206 mm
Top Thickness	14 mm
Bottom Thickness	27 mm
Weight	Approximately 3,500 g
Nationality	Iberian
Marks	None discernable
Location	Sarasota, Florida, USA

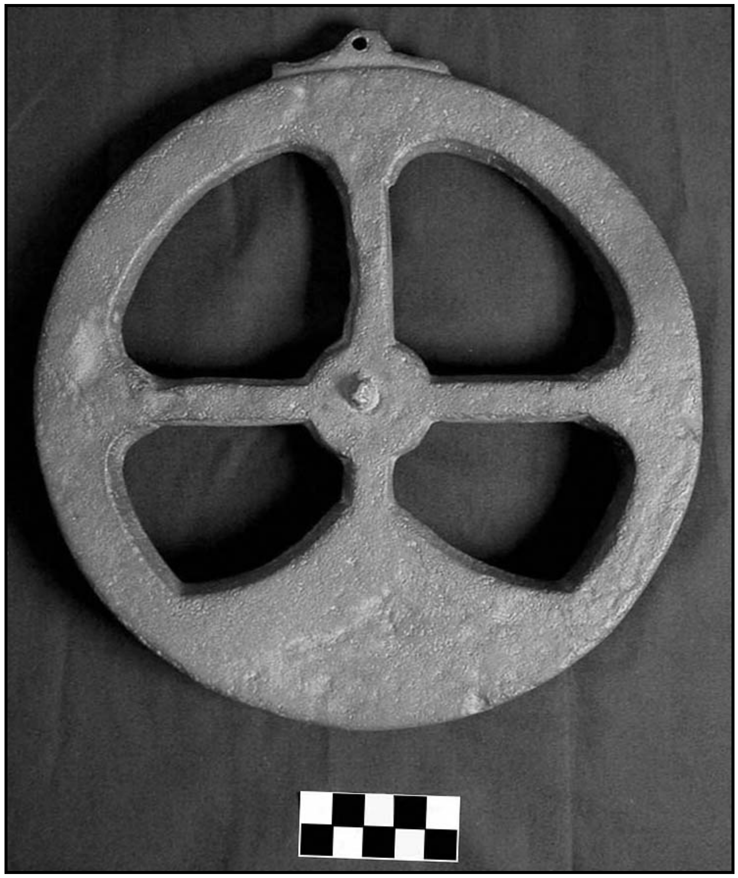

Fig. 30. The fourth astrolabe in the *Seahawk* collection. (Photo by the author)

Mushrow II

Wayne Mushrow, a local milkman and amateur diver, discovered this astrolabe in the summer of 1991 near the coast of Isle aux Morts, Newfoundland, Canada (**Table 14**). The suffix II is due to the fact that Mushrow recovered another astrolabe from that same location on November 1981. The first instrument, originally called the Isle aux Morts astrolabe (NMM 44), was later renamed Mushrow I after its finder. It was dated 1628 and the inscription ‘Y DYAS’ indicated that it was Portuguese.

Various attempts to acquire information on the Mushrow II from Canadian cultural authorities proved fruitless. Therefore, all the information presented here comes from either a Canadian government website,[108] or deduced from a picture provided by Kevin Crisman, of the Nautical Archaeology Program at Texas A&M University (**Fig. 31**). An inscription on the front side of the instrument's ballast reading '1617' indicates the year of manufacture. A second inscription, 'Adrian Holland,' could point to either the maker's name or that of the instrument's owner. Until now, no other astrolabe in the archaeological record bears such a mark. A set of four six-pointed stars may also be seen on each lateral spoke, close to the point where it joins the instrument's rim.

Similarities with the Caudebec astrolabe (1632, NMM 17), destroyed in a bombing during World War II, suggest that the Mushrow II is French.[109] The most remarkable parallel between both instruments is their alidades, which are virtually identical. The astrolabe is graded for zenith distance all around its rim, with the Roman numeral 'V' indicating the multiples of this number in a fashion matching that of the Champlain (Hoffman) astrolabe (1603, NMM 8).[110] The latter was recovered in Canada in 1867 and is also thought to be French.

Table 14. The Mushrow II astrolabe (data and statistics)

Type	Ia
Date	1617
Scales of Limb	0-90-0-90-0
Diameter	Unavailable
Top Thickness	Unavailable
Bottom Thickness	Unavailable
Weight	Unavailable
Nationality	French?
Marks	Various. See text.
Location	Newfoundland Museum, Newfoundland, Canada

The Mushrow II is wedge-shaped, being the latest astrolabe known to have this characteristic. A portion of the suspension ring remains. The instrument seems to be broken in its lower left quadrant. Both Mushrow I and II are likely to have come from the same shipwreck. It has been theorized that it was a French merchantman or fishing vessel that foundered near the coast of Isle aux Morts sometime after 1638.[111] Both instruments are currently stored in the Newfoundland Museum, Newfoundland, Canada.

Fig. 31. The Mushrow II astrolabe. (Photo courtesy of Kevin Crisman)

Passa Pau

This astrolabe was found on 5 November 1999, near the Passa Pau stretch on the eastern coast of São Tiago, the largest island in the Cape Verde archipelago.[112] It was assigned number NMM 84 in the record kept by Stimson. It was later sold at auction by the salvage company Arqueonautas, S.A. and acquired by the Mariner's Museum in Newport News, Virginia. It is a typical Ia astrolabe from the first half of the seventeenth century. The instrument weighs 2,820 g, is 171.5 mm in diameter and 22 mm thick (**Table 15**). It was manufactured in 1645, as shown on the inscription on the front side of the ballast.

The Passa Pau astrolabe was cast from copper alloy and, when finished, was coated with silver. Approximately sixty-five percent of the coating survives (**Fig. 32**). This is unique in the archaeological record thus far. The maker's name, 'NICOLAO RVFFO,' is inscribed below the ballast and is flanked by two six-pointed stars. This instrument shares similarities with the Cádiz I astrolabe (NMM 64), found in 1981 near the coast of Cádiz, Spain, by the crew of a Dutch dredger working in the area.[113]

The Cádiz I was made in 1648, as the inscription on the ballast indicates. Stimson erroneously states that the scale is graded for measuring altitude and concludes that the astrolabe is Spanish. A close look, however, clearly shows that the scale is graded for zenith distance. It may thus be asserted that the Cádiz I is Portuguese, as is the Passa Pau. In the Passa Pau, the zero-degree position is marked with a 'I,' while on the Cádiz I there appear to be no marks.

Table 15. The Passa Pau astrolabe (data and statistics)

Type	Ia
Date	1645
Scales of Limb	90-0-90 (I)
Diameter	171.5 mm
Top Thickness	22 mm
Bottom Thickness	22 mm
Weight	2,820 g
Nationality	Portuguese
Marks	* NICOLAO RVFFO * and date of manufacture within an arrangement of five six-pointed stars
Location	Mariner's Museum, Newport News, Virginia, USA

As with the Passa Pau, the Cádiz I astrolabe has its maker's name inscribed on the rim below the ballast. The inscription reads 'ANDRE RVFFO' and is also contained between two six-pointed stars. A third six-pointed star separates the first from the last name in the Cádiz I, a feature not present in the Passa Pau artifact. Since both makers had the same last name (Ruffo) and worked in Portugal during the 1640s, it is possible that they were related. Furthermore, both instruments share an uncommon feature: three vertical six-pointed stars divide the first two digits of the date of manufacture from the remaining two digits. Another suggestion of relationship between the makers may be found in Stimson’s description of the Cádiz I astrolabe: “… the instrument is complete although it has a strangely rough finish to the casting which slight salt water erosion has not completely disguised.”[114] Did the Cádiz I astrolabe have a silver coating? Both instruments are similar in size, with the Cádiz I having a diameter of 167 mm and a thickness of 20 mm.

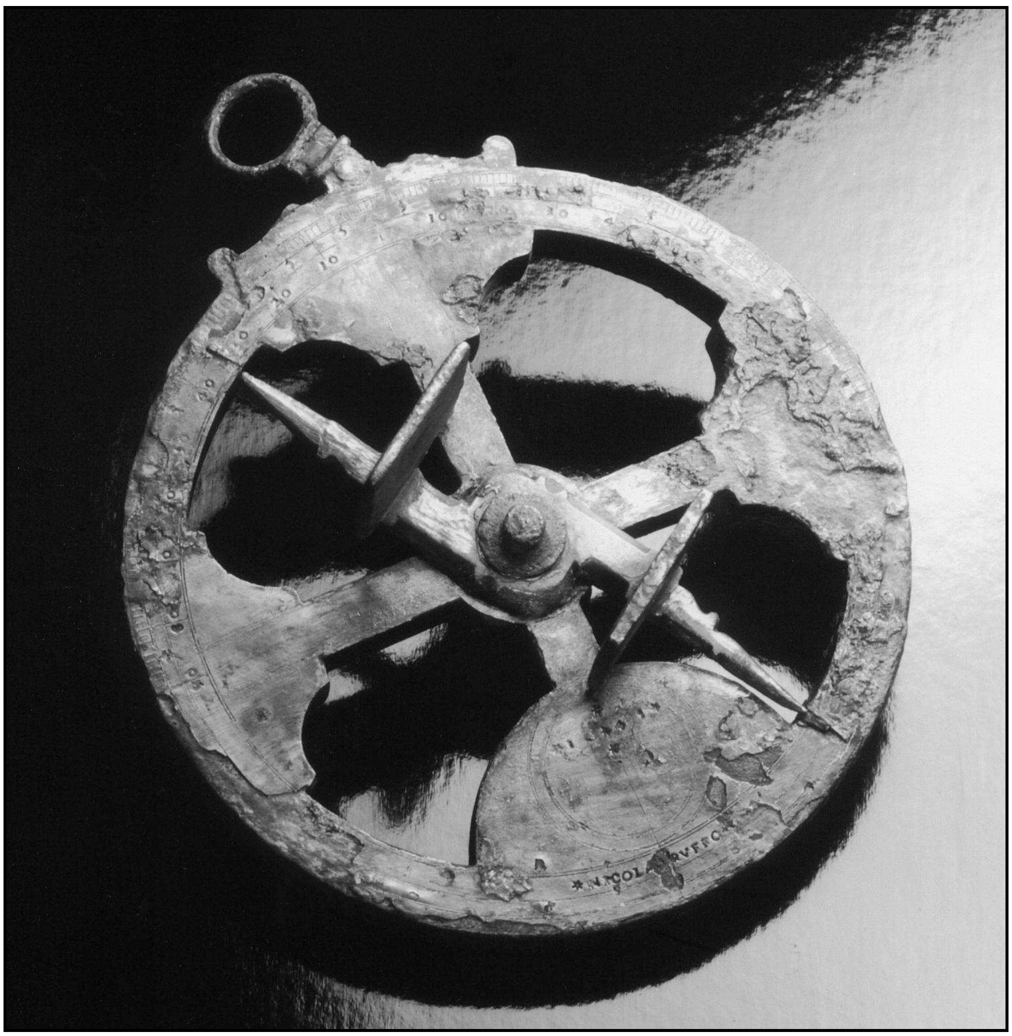

Fig. 32. The Passa Pau astrolabe. (Photo courtesy of the Mariner’s Museum, Virginia, USA)

The alidade of the Passa Pau astrolabe is made of brass and measures 142.2 mm in length. It is nevertheless eroded, and originally would have been approximately 168 mm long. A clear mark at the 34.5-degree position indicates where the extremity of the alidade was positioned when the ship foundered. The two sighting vanes are 54.6 mm apart and have a single perforation of approximately 0.8 mm. On the outer face of each sighting vane, the area around the holes is countersunk approximately 6.7 mm in diameter. A threaded bolt and a wing nut attach the alidade to the hub. It is likely that the alidade was also silver plated. The Passa Pau astrolabe is currently stored at the Mariner's Museum, Newport News, Virginia, USA.

Nassau[115]

The origin of this astrolabe is far from certain. Jeremy Green, of Australia's National Maritime Museum, suggested that it could have been found during underwater operations conducted by Mensun Bound near Malacca, Malaysia, at the wreck site of VOC ship *Nassau.* This vessel burned and sank in battle against the Portuguese in the Strait of Malacca in 1606.[116] The astrolabe never appeared on the excavation records and it was apparently taken to Australia, where it was sold to a private collector.

The diameter was estimated from a scaled picture and it is the largest thus far for any astrolabe from the sixteenth century. Because this instrument was never catalogued, its thickness and weight are unknown (**Table 16**). Pictures provided by Green suggest it is rather thin. The manufacture date, 1568, is inscribed in the bottom ballast between three six-pointed stars located on the sides and top of the inscription. It is likely that a fourth star was present at the bottom, where a void in the metal now exists (**Fig. 33)**.

The astrolabe is fairly well preserved, but a calcareous concretion covers almost three quarters of the rim, three of the four spokes, the hub, the alidade with its sighting vanes and the suspension ring. A round formation close to the hub suggests that a coin is also part of this concretion. The portion exposed shows that the metal was considerably degraded by the action of seawater electrolytes (**Fig. 34**). No scale is discernable in the pictures available. Because of this scant information, it is hard to propose a nationality for this instrument. Its typology, date of manufacture and the place it was found point to an Iberian origin, but its diameter suggests otherwise **(Fig. 35)**.

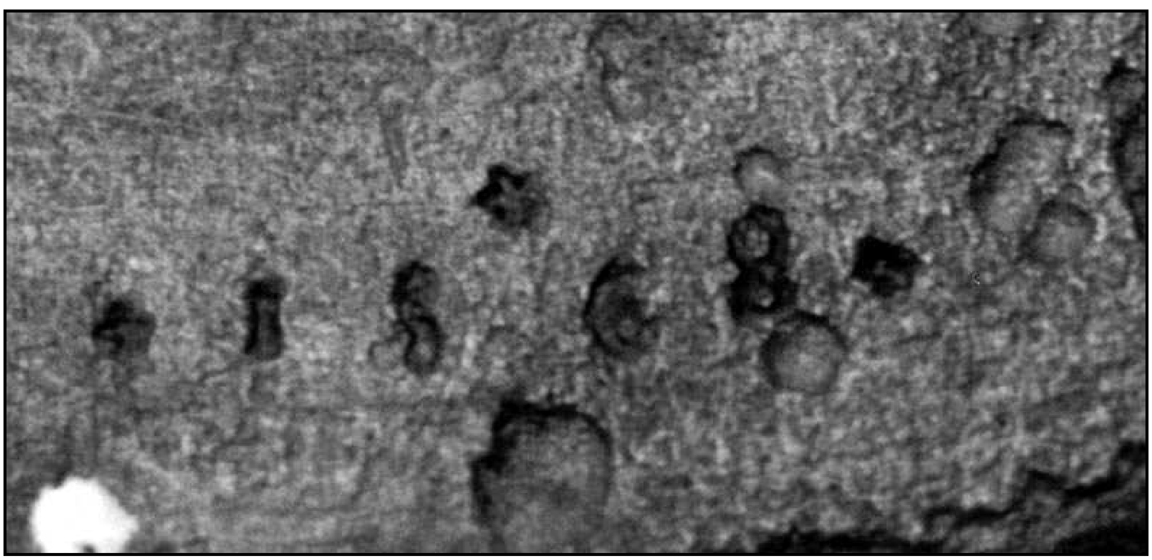

Fig. 33. Date inscription on the *Nassau* astrolabe. (Photo courtesy of Jeremy Green of Australia's National Maritime Museum)

Table 16. The *Nassau* astrolabe (data and statistics)

Type	Ia
Date	1568
Scales of Limb	None discernable
Diameter	Approximately 272 mm
Top Thickness	Unavailable
Bottom Thickness	Unavailable
Weight	Unavailable
Nationality	Iberian?
Marks	Date of manufacture between three six-pointed stars
Location	Private collection, Australia

Fig. 34. Side view of the *Nassau* astrolabe. (Photo courtesy of Jeremy Green of Australia's National Maritime Museum)

Fig. 35. The *Nassau* astrolabe. (Photo courtesy of Jeremy Green of Australia's National Maritime Museum)

CONCLUSIONS

During the years of European maritime expansion and overseas colonization, Puerto Rico, the easternmost island of the Greater Antilles, became a necessary stop for many ships traveling from Europe to the New World. This was the case for vessels coming from Spain. Puerto Rico became a Spanish possession on 19 November 1493 during Columbus' second voyage. Other European countries (*e.g.*, Portugal, England, France, The Netherlands, etc.) would not abide by the papal decrees forbidding them to visit the lands that were by "divine concession" the sole property of the Spanish crown. That is why it is not surprising that on a typical afternoon in the summer of 1987 an unpretentious fisherman stumbled upon the remains of a seventeenth-century ship while repairing the outboard engine of his boat. Although a definite nationality for the vessel was never established, some artifacts recovered from the site point to both England and Spain, two of Europe's most active maritime nations during the period, as their country of manufacture. Even though it has been suggested that the wrecked ship was an English merchantman involved in contraband activities on Puerto Rico's west coast, conclusive evidence to support this statement has never been presented.

The story of the Rincón Astrolabe Shipwreck presents an inglorious case of jurisprudence in the management of submerged cultural resources. The role Puerto Rico played in the process of European colonization of the New World makes it a place of great potential for the development of a comprehensive policy in the administration of underwater archaeological sites. Nonetheless, the 1987 law, established with the intent of managing said policy, proved to be flawed the first time it was applied. The main weakness originates in the section entitled “Economic Benefits; Contracts; First Option.” The opening paragraph reads: “All economic benefit obtained in an authorized operation on an underwater archaeological site shall be shared in a fair manner between he who discovers the site, he who undertakes the operation and the People of Puerto Rico.”[117] The fact that the law provides for those who find and excavate shipwrecks to expect economic compensation, while not establishing its source, allows for cases like this one to fall into an endless legal limbo. Further down in the same section it reads: “The participation of the State of Puerto Rico will never be less than fifty (50) percent of the market value of all the objects recovered, may them be objects of historical, cultural or archaeological value, or economical value uniquely.” The tenets of scientific archaeology dictate that the value of an artifact is purely informational. This means, what it tells us about people and their past. The use of the expression “market value” in Law 10 makes it sound more like a contract between the state and a salvage group in a treasure-hunting venture than the basis on which any government would want to establish the guidelines to protect their country’s submerged archaeological resources.

Besides a brief entry in Stimson’s book, the Rincón astrolabe has never been published. Neither have any of the artifacts recovered at the site. Two pewter plates were exhibited at a local museum in Rincón. However, none of the persons consulted in the making of this document seem to know where these finally wound up. Two harquebuses and numerous other artifacts were sent to a conservation facility in Florida and apparently were never reclaimed. The astrolabe is currently stored in a safe at the

Institute of Puerto Rican Culture's home building in Old San Juan. It is seldom, if ever, displayed.

During the fifteenth century, Portuguese seafarers departed from the traditional navigation technique known as 'dead reckoning' to adopt new systems better suited for their increasingly far-reaching explorations along the West African coast. At stake was the Portuguese crown's desire of finding the much-coveted route to India. The theory that Prince Henry founded a navigator's school in Sagres in the early fifteenth century was undermined during the 1900s. However, no serious scholar would doubt nowadays that the epicenter of this revolution was Portugal and that Prince Henry played a crucial role in its development. For decades, during and after his lifetime, the genius of the Portuguese court was devoted to finding solutions to the problems confronting navigators. The most valuable achievement resulting from this effort was a new method of navigation whereby the position of heavenly bodies above the horizon was measured to determine latitude.

As part of this process, instruments that traditionally belonged to the field of astronomy were adopted and adapted by sea pilots. The most popular were the quadrant, the astrolabe and the cross-staff. None was new to science. All were used by the Muslims during the Middle Ages in astrology, astronomy, land surveying and as time-telling devices. This points to the strong influence that Muslim culture had on European civilization during the eight centuries it remained on the continent (A.D. 711-1492). In navigation, all these instruments were used to determine the altitude of certain celestial bodies. With this measure, and applying the rules codified by astronomers, navigators were able to make an accurate estimate of their position north or south of the equator. It is likely that these instruments were adopted in the order that they are presented in this work. However, none completely superseded the other. Each had its advantages and flaws, and it is likely that a mid sixteenth-century ship carried some of each.

The arrival of the Portuguese and the Spanish to India and the New World was a deed with colossal historical consequences. Still, this phenomenon had further repercussions. Throughout antiquity, and well into medieval times, navigation was based on rudimentary techniques and empirical observations. However, after the fifteenth century, this activity would be inextricably linked to science. Navigation technology progressed in an exponential scale over the next three centuries, a monumental leap over what it had advanced since Pre-Classical times.

Even though the mariner's astrolabe played a vital role in the process of European maritime expansion, it virtually disappeared from written records after the eighteenth century. With the advent of more practical devices and increasingly advanced methods, the instrument was virtually forgotten. However, this was reversed in the early twentieth century, when Portuguese scholar Luciano Pereira da Silva began to publish a series of works on the history of Portuguese navigation in the Age of Discovery. Among them were various articles on sea astrolabes. His initiative served as a catalyst for a newborn interest in the study of Portuguese nautical astronomy, with special emphasis on both instruments and methods. If systematic studies on the nautical astrolabe did not materialize immediately, Pereira's writings paved the way for the appearance of sporadic articles and papers, which culminated in the work by David W. Waters, *The Sea- or*

Mariner's Astrolabe. Based on the foundation laid by Waters and his predecessors, Stimson was able in 1988 to publish what is hitherto the most comprehensive work on the instrument.

The last section of this document presents a catalogue of nautical astrolabes. When the study began in 2001, it was the author's intention to include every instrument that had been registered after 1988. Soon afterwards, it became evident that this was not possible. Astrolabes are an item fiercely sought by private collectors and instruments recovered in operations undertaken with financial purposes usually end up in auction houses. Once the artifacts are sold, it is hard to obtain any relevant information. On occasions, astrolabes are kept in small, remote museums, and contacting the staff is close to impossible. Lastly, the challenges of motivating people to send information of which they are custodians are never ending.

Data on sixteen astrolabes were added to the sixty-five in Stimson's book, for a total of eighty-one. If we add the Zacharchak (NMM 66) and the Ile de Brehat (NMM 85), not included in this work, the total rises to eighty-three. Given that the register number of the Ile de Brehat is NMM 85, we know that there are at least two other recorded astrolabes. However, no information on these artifacts was available to the author.

In the group of astrolabes previously analyzed, certain features may be identified that are worth summarizing. All are type Ia, which attests to the predominance of that kind of instrument. Of all existing sea astrolabes, approximately seventy-eight percent belong in this category. Artifact PE-1, found near reef Inés de Soto, presents a pattern of marks that is unique in the archaeological record. Dated 1555, this is one of the ten oldest nautical astrolabes in existence. The Aveiro astrolabe is, perhaps, the best preserved within its class. The instrument at the *Museo Naval* is unique in its shape. The one found near Francisco Padre, if authentic, is another good example of typical sixteenth-century astrolabe manufacture. The *San Diego* astrolabe is the only specimen in this work for which provenience is known. Its scale, graded but unnumbered, is thus far the second of its kind. The *São Julião da Barra* collection is remarkable because of its size. Even though these astrolabes cannot be definitely related to the wrecked *Nossa Senhora dos Mártires*, they all belong to a similar typology and were manufactured within a relatively short time span.

In the Dry Tortugas Deep Water Shipwreck, we have once more a single site yielding three astrolabes. The *Seahawk* II, with its image of an armillary sphere, presents a rare mark that has not yet been interpreted. Together with the fourth astrolabe purchased by Odyssey Marine Exploration, this assembly constitutes the second largest collection of nautical astrolabes in the world. If there is something interesting about the Mushrow II, it is the fact that Wayne Mushrow found another astrolabe in the same location ten years earlier. This is the only time that two astrolabes have been recovered from a single site by an amateur diver outside an organized archaeological or salvage operation. The Passa Pau has two outstanding features. First, the silver coating, which has no parallel in the archaeological record. Second, there is the inscription 'NICOLAO RVFFO,' similar to the one reading 'ANDRE RVFFO' in the Cádiz I. Last we have the *Nassau* astrolabe, whose large diameter and shape make it a unique instrument.

The history of the mariner's astrolabe is a clear example of how people, in their eternal pursuit of potential glory, adopt existing technologies and improve them. Later, when new challenges require further advances, these technologies are abandoned or taken to more advanced stages. The nautical astrolabe was a practical instrument during the Renaissance. Afterwards, it was abandoned. No person in the twenty-first century would find practical use for a mariner's astrolabe. However, without its existence from the fifteenth to the eighteenth centuries, the maps of our world would be drawn quite differently.

ENDNOTES

1. E. Taylor and M. Richey, *The Geometrical Seaman: A Book of Early Nautical Instruments*, Hollis and Carter (London, 1962), 1.

2. E. Taylor, *The Haven-Finding Art,* American Elsevier Publishing Company, Inc. (New York, 1971), 8-13.

3. E. Taylor and M. Richey, *The Geometrical Seaman: A Book of Early Nautical Instruments*, Hollis and Carter (London, 1962), 3.

4. *Ibid*.

5. E. Taylor, *The Haven-Finding Art*, American Elsevier Publishing Company, Inc. (New York, 1971), 8-13. To understand the use of the North Star (also known as the polestar) in navigation, the reader must be acquainted with two concepts; the "celestial sphere," and the "celestial poles." The celestial sphere is an imaginary globe in which the universe is supposedly contained. In the center of this sphere is the Earth, which remains steady while all the celestial bodies turn around it. The celestial poles are the two points where the axis around which the Earth turns intercepts the celestial sphere. The polestar is the star that is closest to the north celestial pole. Due to the Earth's precessional motion, a different star becomes the North Star approximately every 5,000 years.

6. Throughout this paper, the terms "elevation" and "altitude" refer to the angle formed by a celestial body, the observer (as the vertex) and his horizon.

7. E. Taylor and M. Richey, *The Geometrical Seaman: A Book of Early Nautical Instruments*, Hollis and Carter (London, 1962), 4.

8. D. Cline, *Navigation in the Age of Discovery: An Introduction*, Montfleury, Inc. (Rogers, 1990), 19.

9. E. Taylor, *The Haven-Finding Art*, American Elsevier Publishing Company, Inc. (New York, 1971), 36-37.

10. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 13.

11. P. Ifland, *Taking the Stars: Celestial Navigation from Argonauts to Astronauts*, Krieger Publishing Company (Malabar, Florida, 1998), 3.

12. J. Randier, *Marine Navigation Instruments*, John Murray (London, 1980), 15.

13. E. Taylor and M. Richey, *The Geometrical Seaman: A Book of Early Nautical Instruments*, Hollis and Carter (London, 1962), 6.

14. P. Russel, *Prince Henry "the Navigator": A Life*, Yale University Press (New Haven, 2000), 117-9.

15. W.G.L. Randles, 'The alleged nautical school founded in the fifteenth-century at Sagres by Prince Henry of Portugal, called the "Navigator,"' *Geography, Cartography and Nautical Science in the Renaissance*, Variorum Collected Studies Series (Burlington, 2000).

16. E. Taylor, *The Haven-Finding Art,* American Elsevier Publishing Company, Inc. (New York, 1971), 157.

17. The Portuguese used the term *altura* interchangeably to designate both the altitude of a celestial body and the latitude of a place.

18. R. Anderson, *The Mariner's Astrolabe: An Exhibition at the Royal Scottish Museum*, Royal Scottish Museum (Edinburgh, 1972), 1.

19. The Portuguese estimated that one degree of latitude was equivalent to 16.67 leagues. Therefore, knowing the latitude of two places, they could estimate the north-south distance between them.

20. D. Waters, 'Science and the Techniques of Navigation in the Renaissance,' *Maritime Monographs and Reports*, 19 (1976), 7.

21. This was the committee that in 1483-4, on behalf of King João II, evaluated Columbus' proposal to reach India by sailing west and rejected it.

22. E. Taylor, *The Haven-Finding Art*, American Elsevier Publishing Company, Inc. (New York, 1971), 162.

23. R. Anderson, *The Mariner's Astrolabe: An Exhibition at the Royal Scottish Museum*, Royal Scottish Museum (Edinburgh, 1972), 2. Because the axis around which the Earth turns is tilted 23.5 degrees, the altitude of the sun at noon at any given point varies daily. The term "declination" refers to the angle formed by the sun, the center of the Earth (as the vertex) and the equator.

24. C. Markham, 'The History of the Gradual Development of the Groundwork of Geographical Science,' *Histoire de la Science Nautique des Découvertes Portugaises*

par Joaquim Bensaude, Ministère de L'Instruction Publique de la Rèpublique Portugaise (Lisbon, 1921), 30.

25. E. Taylor, *The Haven-Finding Art*, American Elsevier Publishing Company, Inc. (New York, 1971), 162.

26. Anonymous, *Regimiento do Estrolabio e do Quadrante (1509)*, facsimile edition, Carl Kuhn (Munich, 1914).

27. D. Waters, 'Science and the Techniques of Navigation in the Renaissance,' *Maritime Monographs and Reports*, 19 (1976), 14.

28. Recreating the story of the Rincón Astrolabe Shipwreck was not easy. Many sources were consulted, including governmental and legal reports, newspapers and interviews, both by the author and third parties. It has been almost two decades since the wreck was found, during which the events have lost accuracy in the memory of those involved. Furthermore, the whole matter has been the center of a fierce legal battle that began in 1987. Therefore, individual accounts are likely to be biased. The author has done his best to present the facts objectively. However, the reader must keep all these issues in mind. Especially helpful were the notes provided by Jerome Hall when he was president of the Institute of Nautical Archaeology. While he was the Underwater Archaeologist for the Institute of Puerto Rican Culture (1996), Hall held multiple interviews with the persons involved in this case. His notes were essential in the development of this script.

29. Mikal Woods, a native of Treasure Coast, Florida, worked as a salvage diver for legendary treasure hunter Mel Fisher in the ship *Virgilona*, during Fisher's early career.

30. In personal communications on November 2002 with Peter Hayward, Secretary of The Pewter Society in London, and Jan Gadd, its Librarian, the author learned that Nicholas Kelk completed his apprenticeship, became a Freeman of the Worshipful Company of Pewterers in London and opened shop on 7 February 1638. He was in the parish of St. Michael Cornhill from at least 1648, until his death in 1687. A renowned pewterer, he was Master of the Worshipful Company three times, took on a relatively large number of apprentices and exported a substantial portion of his wares. Besides Puerto Rico, pewter by Kelk was found on the wreck of the Swedish Flagship *Kronan*, which sank off Öland in the south Baltic Sea during battle with a Danish-Dutch fleet in 1676. The pewter belonged to the Lord Admiral of the Swedish Navy, Lorentz Kreutz, and his wife, and it was engraved with their initials in 1671. A pewter plate by Kelk was found in the archaeological excavations of Port Royal, Jamaica, a coastal city that sank in an earthquake on 7 July 1692.

31. Arturo Gandía died around 1993.

32. Fort Buchanan is one of the military bases that the United States Armed Forces keep in Puerto Rico.

33. This account was given to the author by Fitzgerald and Woods in a personal interview held on 4 January 2003. However, in a sworn statement signed by Gandía on 12 January 1995, he declared that nothing was removed from the site that day.

34. On 4 January 2003, Woods told the author that it were he and Rivera who uncovered the astrolabe.

35. On 4 January 2003, Woods told the author that every time the prop wash blaster was used a "cloud of artifacts" arose from the bottom.

36. Aguadilla is a head of district municipality on the northwestern coast of Puerto Rico.

37. Remarkably, the government only confiscated certain artifacts, while others were left to the finders. As of the summer of 2005, one cannon was on display in front of one of Rincon's municipal buildings in a deplorable state of preservation. According to Fitzgerald, he and Woods kept one pewter plate, which they later gave to Rincon's mayor.

38. G. Ponti, *López: galleon trove government property*, San Juan Star, 18 September 1987.

39. According to three newspaper articles, 1,068 artifacts were recovered from the site between December 1986 and August 1987. Most of them were concretions.

40. Puerto Rico, as a protectorate of the United States, is under the jurisdiction of both state and federal laws.

41. W.D. Quevedo, *Nueva disputa por la custodia de un galeón*, Nuevo Día, 10 February 1988.

42. *Government's right to treasure confirmed: Top court ruling based on 1880 Spanish law*, San Juan Star, date unavailable.

43. F. Maddison, 'Medieval Scientific Instruments and the Development of Navigational Instruments in the XVth and XVIth Centuries,' *Revista da Universidade de Coimbra*, XXIV (1969), 13-4.

44. D. Cline, *Navigation in the Age of Discovery: An Introduction*, Montfleury, Inc. (Rogers, 1990), 127.

45. *Ibid.*

46. P. Ifland, *Taking the Stars: Celestial Navigation from Argonauts to Astronauts*, Krieger Publishing Company (Malabar, Florida, 1998), 5.

47. D. García de Palacio, *Instrucción Náutica para Navegar (1587)*, facsimile edition, Ediciones Cultura Hispánica (Madrid, 1944), 23.

48. A. Estácio dos Reis, 'Navegación Astronómica en los Siglos XVI y XVII,' in S. Afonso (ed), *Nossa Senhora dos Mártires: El Último Viaje*, Editorial Verbo (Lisbon, 1998), 87.

49. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 14.

50. A. Estácio dos Reis, 'Navegación Astronómica en los Siglos XVI y XVII,' in S. Afonso (ed), *Nossa Senhora dos Mártires: El Último Viaje*, Editorial Verbo (Lisbon, 1998), 86.

51. D. Cline, *Navigation in the Age of Discovery: An Introduction*, Montfleury, Inc. (Rogers, 1990), 129.

52. D. King, *Islamic Astronomical Instruments*, Variorum Reprints (London, 1987), 43.

53. R. Anderson, *The Mariner's Astrolabe: An Exhibition at the Royal Scottish Museum*, Royal Scottish Museum (Edinburgh, 1972), 3.

54. P. Collinder, *A History of Marine Navigation*, St. Martin's Press (New York, 1955), 117.

55. E. Taylor, *The Haven-Finding Art*, American Elsevier Publishing Company, Inc. (New York, 1971), 90.

56. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 16.

57. D. Waters, 'The Sea- or Mariner's Astrolabe,' *Agrupamento de Estudos de Cartografia Antiga*, XV (1966), 8.

58. *Ibid*, 9-10.

59. *Ibid*, 14.

60. This astrolabe is presented in Stimson's publication (pages 142-3). Stimson shows some hesitancy when referring to the instrument's authenticity, mainly because of certain characteristics in the scale's numbering.

61. D. Waters, 'The Sea- or Mariner's Astrolabe,' *Agrupamento de Estudos de Cartografia Antiga*, XV (1966), 9.

62. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 39.

63. *Ibid*, 24.

64. D. Waters, ‘The Sea- or Mariner’s Astrolabe,’ *Agrupamento de Estudos de Cartografia Antiga*, XV (1966), 15.

65. A. Stimson, *The Mariner’s Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 58-9.

66. M. Cortés, *Breve Compendio de la Sphera y de la Arte de Navegar (1551)*, facsimile edition (cd-rom), Fundación Histórica Tavera (Madrid, 1998), 75-7.

67. D. García de Palacio, *Instrucción Náutica para Navegar (1587)*, facsimile edition, Ediciones Cultura Hispánica (Madrid, 1944), 25.

68. J. Picas do Vale, ‘Astrolabios náuticos,’ in S. Afonso (ed), *Nossa Senhora dos Mártires: El Último Viaje*, Editorial Verbo (Lisbon, 1998), 100.

69. A. Stimson, *The Mariner’s Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 36.

70. *Ibid*, 24-7.

71. M. Cortés, *Breve Compendio de la Sphera y de la Arte de Navegar (1551)*, facsimile edition (cd-rom), Fundación Histórica Tavera (Madrid, 1998), 76.

72. J. Randier, *Marine Navigation Instruments*, John Murray (London, 1980), 84.

73. The wreck of *Nuestra Señora de Atocha* yielded five astrolabes. The next decade, the wreck of *Nossa Senhora dos Mártires* yielded three. So was the case of the Dry Tortugas Deep Water Shipwreck. Two astrolabes were found on a wreck near reef Inés de Soto in Cuba.

74. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 41-2.

75. P. Ifland, *Taking the Stars: Celestial Navigation from Argonauts to Astronauts*, Krieger Publishing Company (Malabar, Florida, 1998), 7.

76. J. Randier, *Marine Navigation Instruments*, John Murray (London, 1980), 82.

77. F. Maddison, 'Medieval Scientific Instruments and the Development of Navigational Instruments in the XVth and XVIth Centuries,' *Revista da Universidade de Coimbra*, XXIV (1969), 47.

78. D. Cline, *Navigation in the Age of Discovery: An Introduction*, Montfleury, Inc. (Rogers, 1990), 135.

79. J. Randier, *Marine Navigation Instruments*, John Murray (London, 1980), 85.

80. F. Maddison, 'Medieval Scientific Instruments and the Development of Navigational Instruments in the XVth and XVIth Centuries,' *Revista da Universidade de Coimbra*, XXIV (1969), 51.

81. H. Wynter and A. Turner, *Scientific Instruments*, Charles Scribner's Sons (New York, 1975), 72.

82. The official register of known mariner's astrolabes was created in the 1980s by Stimson, while he worked at the National Maritime Museum in Greenwich, England. Thus the NMM acronym that precedes the register number of all recorded astrolabes.

83. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 27.

84. Between 1580 and 1640, Portugal and Spain were both under the rule of the Spanish Crown. Therefore, during this period, instrument makers from both nations most likely interacted and both countries shared the equipment used in their ships.

85. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 33-5.

86. D. Waters, 'The Sea- or Mariner's Astrolabe,' *Agrupamento de Estudos de Cartografia Antiga*, XV (1966), 28.

87. A. Estácio dos Reis, *Astrolábios náuticos em Portugal*, Ediçoes INAPA (Lisbon, 2002), 7-9.

88. The word 'authentic' in this sentence refers to the instrument's age, since at the time modern replicas of sea astrolabes already existed in Portugal.

89. This instrument, known to modern scholars as the 'Oxford astrolabe,' was later assigned record number NMM 6 by Stimson and is currently housed at the Museum of the History of Science in Oxford, England.

90. F. da Costa, *A Marinharia dos Descobrimentos*, Agencia Geral das Colonias (Lisbon, 1939).

91. D. Waters, 'The Sea- or Mariner's Astrolabe,' *Agrupamento de Estudos de Cartografia Antiga*, XV (1966).

92. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988).

93. *Ibid*, 11.

94. The official record of known mariner's astrolabes is maintained by Stimson. It is expected that any person or organization that finds an astrolabe contacts him, so that the instrument can be officially registered. Regrettably, this does not always happen and instruments discovered by sport divers and salvagers go without registering. This makes it impossible to know at any given point how many mariner's astrolabes exist.

95. A. Estácio dos Reis, *Astrolábios náuticos em Portugal*, Ediçoes INAPA (Lisbon, 2002), 34.

96. D. Cañizares (ed), *Naufragio en Inés de Soto: un hallazgo de cuatro siglos*, Carisub, S.A. (Havana, 1998).

97. Personal communication with Carmen López Calderón (*Museo Naval*, Madrid), 11 Feb. 2005.

98. The name 'Francisco Padre' was given to this astrolabe by the author. It is likely that this instrument was not officially registered.

99. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 24.

100. The area formed an equilateral triangle seven meters on each side.

101. Notice that the date of manufacture is extended up to *c*. 1625, even though the *Nossa Senhora dos Mártires* foundered in 1606. None of the SJB astrolabes can be conclusively related to this *nau*.

102. J. Picas do Vale, 'Astrolabios náuticos,' in S. Afonso (ed), *Nossa Senhora dos Mártires: El Último Viaje*, Editorial Verbo (Lisbon, 1998), 101.

103. *Ibid*, 102.

104. *Ibid*.

105. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 32-3.

106. The weight of three of the *Seahawk* astrolabes is presented as "approximate," since the scale used to weigh these instruments was not very precise.

107. A. Estácio dos Reis, *Astrolábios náuticos em Portugal*, Ediçoes INAPA (Lisbon, 2002), 34.

108. Government of Newfoundland and Labrador, *Province receives heritage treasures*, accessed 11 Sept. 2005, http://www.releases.gov.nl.ca/releases/2001/tcr/0613n03.htm.

109. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 88-9.

110. *Ibid*, 72-3.

111. Five French coins found at the site by Mushrow in 1981 were dated 1638.

112. B.S. Smith, 'An astrolabe from Passa Pau, Cape Verde Islands,' in *International Journal of Nautical Archaeology*, 31(1), 99.

113. A. Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes*, HES Publishers (Utrecht, 1988), 176-7.

114. *Ibid*.

115. The name *Nassau* was given to this instrument by the author.

116. Communication between Filipe Castro (Texas A&M University) and Jeremy Green (Australia's National Maritime Museum), 17 Oct. 1996.

117. All excerpts from Law 10 have been translated from the Spanish by the author.

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